FROM: Water Quality Control Plan for Salinity, S.F. Bay/Sacramento San Joaquin Delta Estuary 91-15WR May 1991 SWRCB

5.6.1 Present Conditions

5.6.1.1 Background: D-1485 Objectives

Striped bass are specifically protected in D-1485 (Table II,38,39,40). These requirements evolved out of negotiations conducted among DFG, DWR, USFWS, and USBR prior to the 1978 hearing as part of a draft Four-Agency agreement; this agreement was never signed (DFG,25,133). Salinity (EC) objectives at Antioch and at Prisoners Point on the San Joaquin River establish a striped bass spawning area estimated to be about 17 miles in length from April 1 to May 5 in all water years. These objectives were first established (in an earlier form) by Water Right Decision 1379, adopted in July 1971. They were established after a review of an earlier State Board Resolution (68-17; Supplemental Water Quality Control Policy) indicated that striped bass spawning was not being protected. The recommended protection measures were similar to those proposed by a Department of Interior task force on Delta salinity objectives (Decision 1379, 32).

The objective at Antioch is 1.5 mmhos/cm EC (the first two weeks of protection are provided by a Delta Outflow Index requirement of 6,700 cfs rather than an EC objective to provide some ramping capability for the CVP and SWP water projects). This objective also includes a relaxation provision when the SWP or CVP declares deficiencies in delivery of firm project supplies. Upstream, the objectives provide for a maximum of 0.55 mmhos/cm EC at Prisoners Point; no relaxation provision is included.

In May, June and July, minimum Delta Outflow Index flows and limitations on export levels come into effect for protection of young bass. These requirements were designed to help move eggs and young into suitable nursery areas and to reduce entrainment into the SWP and CVP export systems. The Delta outflows were also expected to provide equivalent protection for later spawning in the San Joaquin River, at least in wet, above normal, and below normal water years; outflows during these periods were expected to be higher than the 6,700 cfs estimated to be required to maintain the 1.5 mmhos/cm EC at Antioch under steady-state conditions (1978 Delta Plan, VI-4). Provisions for periodic closure of the Delta Cross Channel gates (to reduce translocation of Sacramento River striped bass eggs and young into the central Delta) and recommendations (not mandatory requirements) for the operation of the projects' fish recovery facilities are included in D-1485. Other than the Delta Cross Channel gate closure, there are no specific objectives for protection of spawning or young bass in the Sacramento River.

5.6.1.2 Current Status

The adult population of striped bass in the Estuary has declined in recent years to about one-third or one-fourth of the population levels seen in the 1960s. A variety of sampling programs are employed to monitor various components of the striped bass population (see Appendix 5.4.1). While the decline rates and patterns may vary somewhat, all programs measuring striped bass abundance show large declines (DFG,25,6,9). The primary means of evaluating the overall condition of striped bass between years has been the Striped Bass Index (SBI). The objectives in D-1485 were designed to maintain the SBI at a long-term average of 79 (the so-called "without project" conditions). This goal has not been achieved; in 1990, the actual SBI reached an all-time low of 4.3; 1988 was the second-lowest on record with 4.6, and in 1989 the SBI was 5.1. The average SBI for the period 1979-1990 is 19.1 (see Appendix 5.4.2).

In the late 1970s declining striped bass populations indicated that the requirements in D-1485 for protection of striped bass were not achieving their intended and expected results. In response, the State Board organized a Striped Bass Work Group composed of staff from several state and federal agencies and outside consultants to investigate the cause(s) of this decline and to make recommendations on actions to correct it. Subsequent discussion and data analysis have resulted in an expanded and refined list of possible causative factors. These are discussed in Appendix 5.4.3. The relationship of the export area striped bass fishery to the Estuary fishery is discussed in Appendix 5.4.4. In large part, while the reasons for the striped bass decline are known, the relative importance of each factor is not completely understood (WQCP-DFG-3).

5.6.2 <u>State Board Considerations</u>

General: Salinity Objectives

Salinity objectives for striped bass apply to the spawning conditions and limitations for adult striped bass in the San Joaquin River. Striped bass in the Sacramento River spawn well above the influence of ocean-derived salinity, and, unlike the San Joaquin River, water quality and river flow are sufficient to prevent the formation of upstream salinity barriers to fish passage due to land-derived salts. No D-1485 objectives or advocated positions consider this area, and no alternatives are offered for consideration.

The D-1485 salinity objectives were expected to provide minimal, yet adequate, spawning habitat from approximately Antioch to Prisoners Point to sustain a healthy striped bass population. However, the continuing decline indicates that some new actions must be considered. Therefore, as one part of an overall program to increase protection for estuarine habitat, it is appropriate to consider modifying the three D-1485 San Joaquin River spawning objectives.

This section considers temperature in addition to salinity objectives at Antioch and Prisoners Point:

5.6.2.1 Antioch: Period of Protection for Spawning
5.6.2.2 Antioch: Relaxation Provision
5.6.2.3 Prisoners Point: EC Modification
5.6.2.4 Prisoners Point: Relaxation Provision
5.6.2.5 Temperature Objectives

5.6.2.1 Antioch: Period of Protection for Spawning

The current D-1485 objectives provide for striped bass spawning protection in the lower San Joaquin River for a period of 35 days, from April 1 to May 5. Protection during the first two weeks of this period is permitted to be met by a Delta Outflow Index (DOI) value of 6,700 cfs, rather than the EC objective of 1.5 mmhos/cm, to provide some operational flexibility for the SWP and CVP without significantly degrading protection of spawning habitat. Since spawning activity is minimal in early April in most years, the small variations in salinity which may occur under this provision are not significant.

After May 5, striped bass spawning habitat is not specifically protected, although spawning in the Delta continues through most of May and occasionally even into June, depending upon water temperatures and perhaps other factors. Some collateral protection is provided by DOI flows designated for protection of young bass. The flow requirements in wet, above normal, and below normal water years are generally sufficient to maintain the 1.5 mmhos/cm EC salinity in the vicinity of Antioch (the lower end of the spawning area) or even farther downstream. However, in subnormal snowmelt, dry and critical water years, DOI requirements are reduced, resulting in loss of spawning habitat. DFG testified that the spawning habitat protection provided under present D-1485 objectives is minimal rather than optimal, and that striped bass would be put under additional stress if the relaxation provision were in effect (see below) (1978 Delta Plan testimony, May 30, 1978, 67:14-19). DFG also testified that the flow requirements (DOI) set for striped bass do not provide adequate protection during dry or critical water years, or those of subnormal snowmelt (T,LXVIII,76:2-4). Therefore, several alternative spawning habitat objectives which provide various levels of protection are considered.

The current objectives provide protection through May 5. Table 5-2 shows the results of DFG egg sampling in the San Joaquin River. For each year, the date on which a specified percentage of total eggs collected is noted. For example, in 1985, 30 percent of the total number of eggs collected by DFG that year were collected by May 1. These data are analogous to, and derived in part from, the cumulative total curves in Turner (1976). This table indicates that a May 5 cutoff date for protection of spawning means that only 30 to 40 percent of the total spawning activity (as measured by eggs collected) in any given year has occurred by that date. The data in Table 5-2 indicate that extending the cutoff date to May 31 protects about 95 percent of the spawning activity in most years.

Alternative levels of protection may be summarized as follows:

TABLE 5-2
STRIPED BASS SPAWNING PATTERNS, SAN JOAQUIN RIVER
PERCENT OF LIVE EGGS COLLECTED, BY DATE
WATER YEAR IS 40/30/30

YEAR	WATER YEAR	PERCENT OF TOTAL EGGS COLLECTED >0	5	10	20	30	40	50	60	70	80	90	95	100
1963*	AN	4/26	5/01	5/05	5/14	5/15	5/16	5/16	5/17	5/19	5/21	5/23	5/27	6/13
1964*	D	4/15	4/15	4/27	5/06	5/15	5/16	5/16	5/17	5/18	5/19	5/23	5/25	6/05
1965*	W	Very few eggs collected; sampling program missed most of spawning; eggs present through 6/19												6/19
1966*	BN	4/14	4/15	4/16	4/20	4/25	4/27	5/01	5/02	5/05	5/07	5/08	5/14	6/18
1967*	W	5/03	5/04	5/04	5/06	5/09	5/17	5/18	5/19	5/20	5/23	6/13	6/18	6/22
1968+	BN	4/03	4/12	4/26	5/02	5/08	5/08	5/08	5/08	5/10	5/10	5/17	5/24	6/14
1969*	W	4/08	4/11	4/15	4/21	5/02	5/08	5/14	5/17	5/20	5/24	5/27	6/01	6/12
1970+	AN	4/21	5/02	5/04	5/05	5/14	5/14	5/15	5/15	5/17	5/18	5/19	5/21	6/30
1971+	W	Sampling begun in late May, eggs present from 5/23 to 7/12; bulk of spawning probably somewhat earlier												7/12
1972+	D	4/29	5/07	5/08	5/10	5/10	5/10	5/11	5/12	5/13	5/19	5/23	5/31	7/06
1973+	AN	Sampling begun in late May; eggs present from 5/29 to 7/04; bulk of spawning probably somewhat earlier												7/04
1975+	W	5/01	5/08	5/11	5/13	5/18	5/21	5/24	5/26	5/27	5/28	6/05	6/06	7/14
1977	C	4/19	4/20	4/21	4/30	5/01	5/01	5/09	5/14	5/15	5/15	5/15	5/28	6/10
1984+	W	4/16	4/23	4/25	5/02	5/07	5/08	5/09	5/13	5/13	5/14	5/15	5/17	7/01
1985+	BN	4/16	4/19	4/24	4/29	5/01	5/03	5/06	5/12	5/13	5/15	5/19	5/22	6/27
1986+	W	4/16	4/21	4/21	4/23	4/30	5/09	5/10	5/11	5/12	5/17	5/22	5/25	7/01
1988+	C	4/12	4/14	4/21	4/23	4/25	4/26	4/27	5/07	5/08	5/09	5/18	5/24	6/15
1989+	D	4/12	4/17	4/18	4/20	4/24	5/03	5/04	5/05	5/06	5/10	5/26	6/01	6/23
AVERAGE DATE OF COLLECTION FOR PERCENT INDICATED		--	4/23	4\26	4/30	5/05	5/08	5/11	8/13	5/14	5/17	5/22	5/27	6/21

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* = Values derived from curves in Figure 2 of Turner (1976);
remaining years from cumulative totals of live eggs from DFG data (Lee Miller)

+ = Eggs present on first day of sampling (date in >0 column); some spawning probably occured prior to date shown

Alternatives	Approximate percent of spawning activity protected
1. April 1 through May 5, with ramping* (present condition)	30-40%
2. April 15 through May 15, without ramping	55-65%
3. April 1 through May 15, with ramping	60-70%
4. April 15 through May 31, without ramping	90%
5. April 1 through May 31, with ramping	95%
6. April 1 through May 31, without ramping	>95%

* ramping = 6,700 cfs Delta Outflow Index value for period April 1 through April 14

The percent of spawning activity assumed protected under each alternative in the table above is determined directly from Table 5-2. The range of percent spawning activity protected is simply the amount of spawning activity measured (i.e., percent of total eggs collected) by the end date of each alternative. There is assumed to be relatively little spawning which occurs before about April 15 each year, so the absence of ramping (i.e., appropriate salinity from April 1 rather than ramping flows to April 14) was assumed to add only about 5 percent additional spawning activity protection over that provided by ramping. The relative lack of data before April 15 makes this somewhat speculative, but in any case it is probably not significant.

The State Water Contractors proposed extending protection of spawning activity only to May 21 in dry and critical years (WQCP-SWC-627,3-4).

The present Antioch standard of 1.5 mmhos/cm EC was primarily designed, as is described in Section 5.6.1.1, to provide a suitable spawning habitat upstream of Antioch, not at the Antioch location itself. According to the recollection of Don Stevens of DFG (pers. comm., 3/91), Antioch was chosen as a monitoring point because a salinity monitoring station was already established at the Antioch Water Works. The use of 1.5 mmhos/cm EC at Antioch for spawning protection appears not to be generally appropriate, since DFG's own testimony indicates that striped bass prefer to spawn in freshwater, and that a spawning objective of 0.44 mmhos/cm EC represents the "best scientific evidence" of the water quality needed to restore spawning in the historical spawning area of the San Joaquin River (DFG-WQCP-9,4) (see Section 5.6.2.3). However, the Antioch water quality objective may continue to serve the purpose of being an ultimate delimiter of spawning habitat; the Antioch objective can also be considered an "implementing measure" since maintaining that objective should produce less saline, and thus more suitable habitat, upstream of Antioch in the San Joaquin River. DFG has observed some spawning in the Antioch to Jersey Point reach, sometimes in ECs of 1.5 mmhos/cm or higher, in some very dry years (1972 and 1977). Laboratory studies also indicate that egg survival is not affected adversely in water with ECs up to 1.5 mmhos/cm (DFG,25,46). These conditions have typically produced some of the lowest abundance indices, however. We also agree that the striped bass spawning objectives, as proposed, do not in fact designate a spawning reach, but only a single location (Prisoners Point) where appropriate salinities for the majority of spawning, as determined by DFG, are required to be present.

5.6.2.2 Antioch: Relaxation Provision

Decision 1485 provides for a relaxation of the protection for striped bass spawning when the SWP or CVP impose deficiencies in their firm supplies. The EC objective is relaxed proportional to the amount of deficiency imposed. Under extreme conditions, when the projects impose deficiencies of 4.0 MAF or more, D-1485 in theory allows the EC at Antioch to degrade to 25.2 mmhos/cm, which would result in substantial reduction of spawning habitat to an estimated reach of about 9.5 miles or less (Delta Plan and D-1485 Final EIR,V-24 to V-26). However, it was believed that the Suisun Marsh protection objectives (critical years) or Delta agricultural objectives (dry years) would in fact control salinity in the lower San Joaquin River throughout the month of May. Therefore, the actual EC at Antioch, regardless of the size of the deficiency imposed, was not expected to exceed 3.7 mmhos/cm in critical years, and 1.8 mmhos/cm in dry years (letter from SWRCB to EPA April 3, 1979 -- information based on DWR 1978 Hearing Ex. 7B).

As several participants have pointed out, there is considerable confusion about the appropriateness of the proposed relaxation criteria, in terms of what salinity is appropriate at Antioch for various deficiency levels. As has been discussed, the 1978 Delta Plan and EIR based the relaxations on a salinity/flow relationship for the Sacramento River, which was assumed to be applicable to the San Joaquin River as well. In addition, the theoretical extent of salinity degradation was supposedly limited to a maximum of 3.7 mmhos/cm EC because of the Chipps Island Suisun Marsh standard. The entire process is built on a series of artificial relationships which are unrelated to the main issue at hand, which is the establishment and maintenance of suitable spawning habitat for striped bass in the San Joaquin River and the relaxation of that habitat requirement when water project firm deliveries are reduced.

The State Board continues to believe that, as stated in its conclusions on striped bass (Section 5.6), the "[d]eficiencies in firm supplies and the level of protection afforded by the striped bass spawning objective should be correlated." The present deficiency schedule does not do that, since no specific relationship between extent of habitat and change in salinity intrusion has been made. The present relationship is based on a Sacramento River salinity/flow relationship. Several participants have appropriately questioned the basis for this relationship.

In 1990, the projects declared a deficiency and invoked the relaxation provision. Despite compliance with other D-1485 standards, the theoretical expected Antioch maximum EC of 3.7 mmhos/cm was exceeded. In addition, monitoring data from 1990 suggest that ECs greater than 0.44 mmhos/cm occurred throughout nearly all of the striped bass spawning area, not simply at the downstream end.

The State Board would like to relate deficiencies to spawning area in a direct, measurable way: by simply making increases in deficiencies directly related to the shortening of the length of river reach in which suitable spawning habitat will be required to be maintained. The Board believes this approach would have a negligible effect on water supplies during most years because D-1485 provides some umbrella spawning protection upstream of Antioch by means of the central and western Delta agricultural standards. These standards are presently under review, and the required water quality at some locations may be reduced (salinity increased). By establishing a separate spawning habitat objective, no re-evaluation of the effects of water quality degradation on striped bass habitat will be required. The present agricultural water quality objective includes a level of 0.45 mmhos/cm EC at Jersey Point from April 1 to August 15 (in all but critical years). This objective essentially duplicates the current EC and starting date requirements for striped bass spawning protection. In Section 7.5.2.4, Program of Implementation, the State Board outlines a proposal for evaluation of the concept of establishment of a specific spawning protection zone and a directly related relaxation provision.

5.6.2.3 Prisoners Point: EC Modification

The D-1485 objective for EC at Prisoners Point on Venice Island is 0.55 mmhos/cm for the period April 1 to May 5, in all water years, to delimit the upstream end of the San Joaquin River spawning area. No relaxation provision for deficiencies is included. Transfer of water across the Delta to the export pumps results in relatively low salinity in the Prisoners Point area of the San Joaquin River. Salinity in the San Joaquin River increases upstream of Prisoners Point due to reduced freshwater inflow and saline agricultural return flows from the eastern and southern Delta and from the River above the Delta. Thus, the absence of salinity objectives above Prisoners Point effectively establishes a barrier to adult migration and spawning farther upstream on the San Joaquin River.

Three issues are involved with this standard: period of protection, extension of spawning habitat farther upstream, and appropriate EC levels.

Period of Protection

As noted above, there is substantial spawning in the Delta throughout May. Flows through the Mokelumne River system, especially the movement of Sacramento River water through the Delta Cross Channel, most likely provide considerable protection of water quality in the area around Prisoners Point throughout much of the spring months.

For consistency with the objectives proposed for Antioch, the State Board will examine the effect of setting the same period of protection as at Antioch: April 1 to May 31 in all water years.

Extension of Available Spawning Habitat Upstream

The major issue involving the current striped bass spawning objectives is whether the spawning area should be expanded beyond its present size. The present objective results in substantial spawning in the channels which move water to the export pumps in the south Delta; for part of the spawning period (April), there are no restrictions on export rates. This undoubtedly results in substantial losses of eggs and young. In its comments on the proposed objectives in D-1485, DFG noted that the designated spawning area provided "minimal suitable conditions" (Testimony, 1978 Delta Plan, 4/27/77, XXII, 160:17-19).

In Phase I, DFG testified that striped bass used to spawn farther up the San Joaquin River than at present, but do not do so now because of increased salinity (T,XLI,68:3-20). Despite testimony to the contrary (see for example, U.S. Department of Interior comments, 4/23/90, p.6), numerous records from the early decades of this century indicate that striped bass regularly migrated up the San Joaquin River and its tributaries. As late as 1963, substantial spawning in the San Joaquin River occurred in the reach between Stockton and Mossdale (Farley, 1966). Spawning occurred above Vernalis in 1968, with many of the eggs appearing near Patterson, 104 miles above the mouth of the river (Turner, 1976). In wetter years large striped bass are still seen in the San Joaquin River tributaries (W. Loudermilk, DFG, pers. comm., 1988). It appears that the upper Delta and the tributary rivers may still support striped bass spawning when appropriate habitat conditions are provided.

On the other hand, several arguments have been offered to support retention of the present objective (limit spawning to west of Prisoners Point). These arguments are based primarily on two factors: (1) assumptions that eggs and young that were produced farther upstream would be carried to the export pumps and lost to the Delta; and (2) lack of a strong experimentally-derived correlation between salinity and spawning success. These arguments are discussed in Appendix 5.4.5.

Appropriate Electrical Conductivity Levels

The Phase I testimony and exhibits indicate that striped bass prefer to spawn in water with an EC of less than 0.3 mmhos/cm (TDS=170 mg/l) (DFG,25,46 and 47). Farley (1966) concluded that striped bass require a TDS of less than 250 mg/l (= 0.44 mmhos/cm EC). It is DFG's belief that this represents the "best scientific evidence" to restore spawning in the historical spawning area of the San Joaquin River (WQCP-DFG-4,9). Higher salinities may affect egg survival as well as spawning activity. Turner (1976) found that, in water of 600-800 mg/l TDS (= 1.03-1.36 mmhos/cm EC) on the San Joaquin River above the Delta in 1968, 94 percent of the eggs he collected were dead. However, it is not clear whether this high percent of dead eggs was caused by salinity or some other factor.

Establishing an objective of 0.55 mmhos/cm EC in the reach from Prisoners Point to Vernalis would not expand the spawning area since, based on prior testimony, that EC level would still act as a barrier to migration upstream of Prisoners Point. Likewise, establishing any objective at a single location well up in the Delta (such as at Vernalis) will not assure that the intervening stretch of river will be of quality adequate for spawning. The appropriate objective must be applied at several points along the San Joaquin River to assure continuity.

5.6.2.4 Prisoners Point: Relaxation Provision

The D-1485 objective for Prisoners Point did not include a relaxation provision. However, consideration of a relaxation provision is appropriate, should one of the alternatives which improve water quality above the present objective of 0.55 mmhos/cm EC be selected.

5.6.2.5 Temperature Objectives

Evidence presented in Phase I, and analysis of other data, indicate that high water temperatures may result in some possible losses of bass eggs and young. However, these losses are not considered significant. Temperature issues are discussed in Appendix 5.4.6. Based on the information available, no special measures are warranted at this time.

5.6.3 <u>Potential Objectives</u>

In view of the above considerations, the State Board has developed the following potential objectives at these locations, in addition to the possible retention of the current objectives.

5.6.3.1 Antioch: Period of Protection for Spawning
5.6.3.2 Antioch: Relaxation Provision
5.6.3.3 Prisoners Point: EC Modification
5.6.3.4 Prisoners Point: Relaxation Provision
5.6.3.5 Temperature Objectives

5.6.3.1 Antioch: Period of Protection for Spawning

Objective 1-A The 14-day running average of the mean daily EC at the Antioch Waterworks Intake on the San Joaquin River shall be not more than 1.5 mmhos/cm for the period April 1 to May 31, or until spawning has ended, in all water years.

Objective 1-B The 14-day running average of the mean daily EC at the Antioch Waterworks Intake on the San Joaquin River shall be not more than 1.5 mmhos/cm for the period April 1 to May 31, or until spawning has ended, in all water years, except that protection during the period April 1 to April 14 may be provided by maintenance of an average Delta Outflow Index for that period of not less than 6,700 cfs.

Objective 1-C The 14-day running average of the mean daily EC at the Antioch Waterworks Intake on the San Joaquin River shall be not more than 1.5 mmhos/cm for the period April 1 to May 31, or until spawning has ended, in wet, above normal, and below normal water years; or for the period April 1 to May 21, or until spawning has ended, in dry and critical water years; except that protection during the period April 1 to April 14 in all water years may be provided by maintenance of an average Delta Outflow Index for that period of not less than 6,700 cfs.

5.6.3.2 Antioch: Relaxation Provision

Objective 2-A No relaxation provision.

Objective 2-B The 14-day running average of the mean daily EC at the Antioch Waterworks Intake on the San Joaquin River shall be not more than the values (shown in the table below) corresponding to the deficiencies in firm supplies declared by the SWP and CVP, in dry and critical water years, for the period April 1 to May 31, or until spawning has ended.

Total Annual Declared Deficiencies (MAF)	April 1 to May 31 EC in mmhos/cm	
	Dry	Critical
0.0	1.5	1.5
0.5	1.8	1.9
1.0	1.8	2.5
1.5	1.8	3.4
2.0 or more	1.8	3.7

Linear interpolation is to be used to determine values between those shown.

Objective 2-C Same as 2-B, except that deficiencies are defined as deficiencies in firm supplies declared by a set of water projects representative of the Sacramento River and San Joaquin River watersheds. The specific representative projects and amounts of deficiencies would be defined in subsequent phases of the proceedings under this alternative.

Objective 2-D Same as Objective 2-B or 2-C except the period of protection is April 1 to May 21.

Objective 2-E The 14-day running average of the mean daily EC at the Antioch Waterworks Intake on the San Joaquin River shall be not more than 3.7 mmhos/cm for the period April 1 to May 31, or until spawning has ended, when the April 1, 40-30-30 Sacramento Basin Index is equal to or less than 4.8 MAF.

5.6.3.3 Prisoners Point: EC Modification

Objective 3-A The 14-day running average of the mean daily EC shall be not more than 0.30 mmhos/cm (TDS=170 mg/l) for the period April 1 to May 31, or until spawning has ended, in all water years, at the following stations: Prisoners Point, Buckley Cove, Rough and Ready Island, Brandt Bridge (site), Mossdale Bridge, and Vernalis.

Objective 3-B The 14-day running average of the mean daily EC shall be not more than 0.44 mmhos/cm (TDS=250 mg/l) for the period April 1 to May 31, or until spawning has ended, in all water years, at the following stations: Prisoners Point, Buckley Cove, Rough and Ready Island, Brandt Bridge (site), Mossdale Bridge, and Vernalis.

Objective 3-C The 14-day running average of the mean daily EC shall be not more than 0.44 mmhos/cm (TDS=250 mg/l) for the period April 1 to May 31, or until spawning has ended, in wet, above normal, and below normal water years; or for the period April 1 to May 21, or until spawning has ended, in dry and critical water years, at the following stations: Prisoners Point, Buckley Cove, Rough and Ready Island, Brandt Bridge (site), Mossdale Bridge, and Vernalis.

Objective 3-D The 14-day running average of the mean daily EC shall be not more than 0.44 mmhos/cm (TDS=250 mg/l) for the period April 1 to May 31, or until spawning has ended, in wet, above normal, and below normal water years, at the following stations: Prisoners Point, Buckley Cove, Rough and Ready Island, Brandt Bridge (site), Mossdale Bridge, and Vernalis. In dry and critical water years, the EC objective would be met only at Prisoners Point.

Objective 3-E The 14-day running average of the mean daily EC shall be not more than 0.44 mmhos/cm (TDS=250 mg/l) for the period April 1 to May 31, or until spawning has ended, at the following river reaches in the respective water years:

Wet	Prisoners Point to Vernalis
Above Normal	Prisoners Point to Mossdale Bridge
Below Normal	Prisoners Point to Rough and Ready Island
Dry	Prisoners Point to Buckley Cove
Critical	Prisoners Point only

Objective 3-F The 14-day running average of the mean daily EC at Prisoners Point shall be not more than 0.44 mmhos/cm (TDS=250 mg/l) for the period April 1 to May 31, or until spawning has ended, in all water years.

5.6.3.4 Prisoners Point: Relaxation Provision

Objective 4-A No relaxation provision.

Objective 4-B The 14-day running average of the mean daily EC shall be not more than 0.55 mmhos/cm for the period April 1 to May 31, or until spawning has ended, at Prisoners Point only, when the Antioch relaxation provision for spawning protection is in effect.

(It can be argued that the use of the Sacramento Basin 40-30-30 Water Year Index, or SWP and CVP deficiency declaration, to trigger a relaxation on an upper San Joaquin River objective is inappropriate. However, since consensus has not yet been reached on an appropriate San Joaquin Basin Index, it cannot be applied here. On the other hand, the hydrologic record shows that a critical year in the Sacramento Basin is almost always accompanied by similar conditions in the San Joaquin Basin. The State Board urges participants to complete development of a San Joaquin Basin Index for application to upper San Joaquin River objectives as soon as possible.)

5.6.3.5 Temperature Objectives

No temperature objectives are proposed at the present time for protection of adult striped bass migration and spawning, or for survival of young striped bass.

5.7 American Shad

5.7.1 Present Conditions

There are no D-1485 objectives specifically for the protection of American shad, although the striped bass standards were expected to provide collateral protection for American shad as well. DFG estimates of population size based on sampling in the mid-1970s suggest that the population is one-third to two-thirds as large as it was in the early decades of this century (DFG,23). About this same time, DFG lowered the daily catch limit from 50 to 25 fish (Michael Meinz, SWRCB, pers. comm., 6/90). Abundance of adult shad has been relatively stable over the past two decades. However, abundance of juvenile shad may vary by more than an order of magnitude between years, with the strongest year classes occurring with the highest river flows during the spawning and nursery periods (DFG,23).

5.7.2 State Board Considerations

The decline of American shad in the Estuary from levels found early in the century appears to parallel, although perhaps not so severely, the great decline seen in East Coast shad populations (USFWS & NMFS, 1977, viii). Declines in East Coast stocks have been attributed to a variety of causes, including pollution, lack of floodplain management, construction of barrier dams without fish passage facilities, and expanded and indiscriminate inshore and offshore fishing (USFWS & NMFS, 1977, vii-viii). Most of these elements may also be playing a part in the decline in Estuary stocks (DFG,23,23), although DFG cites flows and diversions as the primary areas of concern (T,XXXIX,16:4-18:18;47:7-16). DFG also testified that temperature and salinity, as well as flow, were important to production of American shad (T,XXXIX,24:22-25:1), but did not specify what temperature and salinity requirements were critical to shad production.

shad abundance vs. flow -

Central Valley Salmon and Steelhead Restoration and Enhancement Plan

April 1990

RESOURCES AGENCY
CALIFORNIA
DEPARTMENT
FISH & GAME

Temperatures critical to salmon inland life history are as follows:

Critical Factor	Degrees Fahrenheit
Spawning	42-57.5
Incubation	53-57.5
Preferred rearing	53-57.5
Maximum growth	54-60
Growth ceases	65-69
Lethal	77

Depending upon the river reach and the timing for each life stage of each race of chinook salmon, the objectives for various river reaches will differ. However, to ensure growth and to control the virulence of common fish diseases, rearing temperatures must be maintained below 65°F, and in no case should water temperatures be allowed to reach 77°F. For incubation of eggs, 56°F must not be exceeded.

Other water quality parameters such as heavy metals, turbidity, dissolved oxygen, etc., are thoroughly addressed in the <u>Water Quality Plan Report.</u> The attainment of these objectives would benefit salmon and steelhead and should be strongly supported.

Flow objectives, like temperature, will be specific for each river to maximize salmon and steelhead production. Generally, however, flows must be sufficient to allow successful immigration and spawning of adults and incubation, rearing, and emigration of smolts to the ocean.

<u>Migration.</u> Flows must be sufficient to allow fish to safely pass all critical riffles, fish ladders, channel bifurcations, diversions, or any other obstruction they may encounter during their upstream migration.

<u>Spawning.</u> Successful spawning flows are determined by depth and velocity of water over the spawning beds. The general goal for spawning habitat, therefore, is a water depth of 1.5-3.0 feet and a velocity of 1.0-3.5 fps. Winter-run chinook salmon spawning preference may significantly vary from this standard.

<u>Incubation.</u> Flows must be sufficient to maintain water over the redds with a velocity less than that which would displace the gravels. Intergravel flow should be at least 26 feet per hour to provide adequate oxygen and removal of metabolic wastes.

<u>Rearing.</u> Water flows needed for successful rearing must be sufficient to allow the young fish in shallow water areas to escape predation and, also, sufficient to raise aquatic invertebrates which the young fish rely for food. Each river will require different flow regimes to attain these goals.

<u>Emigration.</u> Successful downstream migration of salmonid smolts is critical for the restoration of wild stocks of salmon and

August 20, 1991

MEMORANDUM

TO: Patrick Wright

FROM: Susan Hatfield

RE: Effect on Chinook Salmon survival of Lowering Temperature Standard at Freeport from 68° to 65° F

Based on the USFWS' "Model for Estimating Mortality and Survival of Fall-run Chinook Salmon Smolts in the Sacramento River Delta Between Sacramento and Chipps Island", the major variables affecting smolt survival are temperature, diversion into the Central Delta, and water export. Under current conditions (D1485), the May and June export levels are approximately 6,000 cfs, and the diversions between 50 and 70%. Exports could be as low as 3,000, and diversions as low as 30% under the best water year conditions (i.e. spring 1983, a wet year). Under this range of conditions the estimated smolt survival at 60°, 65° and 68° F is:

Temp. at Freeport	% diverted	export	survival
60°	.70	6,000	.36
	.30	3,000	.55
65°	.70	6,000	.19
	.50	6,000	.23
	.30	3,000	.31
68°	.70	6,000	.11
	.50	6,000	.14
	.30	3,000	.19

Therefore the additional survival gained (during those times temperature is controlled to meet the standards) by lowering the standard from 68° to 65° is between .08 and .12. As a percent increase in survival this change is substantial. The percent increase (over survival at 68°) is between 63% and 72%.

United States Department of the Interior

FISH AND WILDLIFE SERVICE

Fish and Wildlife Enhancement
Sacramento Field Office
2800 Cottage Way, Room E-1803
Sacramento, California 95825-1846

TAKE PRIDE IN AMERICA

FWI

August 16, 1991

21 AUG 1991
RA/DRA
Action W-1
CC:
File:

Mr. Gary Stern, Fishery Biologist
National Marine Fisheries Service
777 Sonoma Avenue, Room 325
Santa Rosa, California 95404

Subject: Winter-run chinook salmon biological criteria

Dear ~~Mr. Stern~~ Gary:

This responds to your July 16, 1991 memorandum requesting our review of draft winter-run salmon biological criteria for use in the development of a Central Valley Project operations plan. We have reviewed the draft criteria and offer the following comments.

1. Red Bluff Diversion Dam Passage.

   Adult — In addition to the suggested method, you might add: "If gates are in place, modify fishways to convey 10-15 percent of flows passing RBDD to provide for adequate upstream attraction and passage."

   Spawning — The requirements should include measures that will ensure spawning populations are able to successfully migrate past the RBDD and reach favorable spawning habitats as far upstream as possible. Suggested methods could include (1) delay in closing gates as long as practicable, and (2) release of warm surface water from Lake Shasta to encourage upstream migration.

2. Streamflows.

   Spawning — Is 8,000 cfs in normal water years defensible? We are concerned about mandating 8,000, if 6,000 cfs provides sufficient habitat, and then running into redd dewatering or water quality problems in the summer and fall because 8,000 cfs was maintained through the incubation period.

3. Water Quality.

   Adult — For dissolved oxygen, add not less that 7.0 mg/l.

4. Keswick Fish Trap.

   We suggest you add "and effective operation at higher flows"

5. There is no mention of the Anderson-Cottonwood Irrigation District Diversion Dam. The Bureau of Reclamation modifies flow regimes as necessary for the installation, removal and adjustment of flashboards at

the ACID Dam. Some of these flow modifications may be deleterious to winter-run salmon, such as when flows are reduced in the spring spawning period to install the flashboards, or reduced in the fall to allow for flashboard removal. Dewatering redds, disrupting spawning activity, and stranding juvenile winter-run chinook salmon occasionally result from Bureau flow adjustments to accommodate the ACID. Operation of the diversion dam itself is adverse to winter-run salmon, resulting in (1) reduced spawning and incubation habitat in Lake Redding when water elevation is raised and water velocity is lowered following flashboard installation, (2) blockage of spawners from upstream habitat due to inadequate fish passage facilities, and (3) reduction of potential brood stock for the artificial propagation program at Coleman National Fish Hatchery because of the inability of fish to reach the Keswick Fish Trap.

6. Lower Sacramento ~~(City of Sacramento to Chipps Island)~~.
Temperature Requirements--to the extent controllable

Adult	less than or equal to 60°F
Juvenile	less than or equal to 58°F

Maintaining these water temperatures in the Delta, especially for juveniles during the early fall and late spring, would be highly improbable, and if done, would have major impacts on other species in the Delta and Sacramento River. Such temperatures are suitable for rearing fish, but a higher water temperature is acceptable for smolt passage. Perhaps another category should be included:

Smolt	less than or equal to 65°F

Thank you for the opportunity to comment on these criteria. If you have any questions, please contact staff biologist Tom Richardson at (916) 978-4613. We understand that additional comments may be provided directly to you from the Service's Fishery Resource Offices in Red Bluff and Stockton.

Sincerely,

Wayne S. White
Field Supervisor

cc: Reg. Dir., AFWE, FWS, Portland, OR.
Project Leader, NCVFRO, FWS, Red Bluff, CA
Dir., CDFG, Sacramento
Reg. Mgr., CDFG, Region 1, Redding
Project Leader, FRO, FWS, Stockton
Lewiston Substation, FWS, Lewiston
Reg. Admin., EPA, San Francisco

Upper Sacramento River
Fisheries and Riparian Habitat Management Plan

Prepared for The Resources Agency
by an Advisory Council established by
SB 1086, authored by Senator Jim Nielsen

January 1989

Gordon K. Van Vleck
Secretary for Resources
The Resources Agency

George Deukmejian
Governor
State of California

Lower Sacramento River Temperature – Colusa Drain

Purpose

The purpose of this action is to increase survival of emigrating salmon smolts through the lower Sacramento River and Delta by decreasing water temperatures in late April through June.

Background

Water temperatures in the lower Sacramento River below Knights Landing during May and June can exceed 70 degrees F, temperatures detrimental to salmon smolts. The majority of salmon smolts generally emigrate from the upper Sacramento River in May and early June. High water temperature has been implicated in the decline of the upper Sacramento River chinook salmon runs. The Colusa Drain is a major contributor of warm water to the Sacramento during this period. Flows in the Colusa Drain occasionally exceed 2,000 second-feet with water temperatures over 80 degrees F.

Discussion

The U.S. Corps of Engineers studied solutions to the flooding problems of the lower Colusa Drain. Their reconnaissance report, dated June 1968, included a project to take Colusa Drain flows south into the Yolo Bypass channels by deepening and widening the Knights Landing Ridge Cut, an existing channel that now takes some Colusa Drain water south for irrigation in the bypass (see map). Improvements to the Ridge Cut and Yolo Bypass channels were estimated to cost $810,000 in 1968, which would be about $3 million, updated to 1988 cost levels.

Construction of this added channel capacity would allow routing of the warm Colusa Drain flows into the Yolo Bypass, which returns to the Sacramento River just upstream from Rio Vista. Emigrating smolts would thus have cooler water in about 40 miles of the Sacramento River, but would still have to deal with this warm water for about 10 miles before reaching Suisun Bay. Agricultural diversions from the bypass should reduce the volume reaching the river and thus reduce warming in this last 10 miles.

Another potential solution to the warm water problem is to increase the flows of colder water. Two possibilities exist: (1) large increases into the Feather River from Oroville, or (2) smaller flow increases from Nimbus Dam to the American River. These possibilities, especially the latter, would be substantially more feasible if the Colusa Drain flows were rerouted. A feasibility study is needed to determine the viability of these solutions.

Recommended Solutions

1. Investigate the feasibility of rerouting Colusa Drain flows from late April through June into the Yolo Bypass by constructing a larger Knights Landing Ridge Cut and improving the Bypass channels.

2. Investigate the feasibility of lowering Sacramento River water temperatures to 65 degrees F or less by increasing flows in late April through June in the American and/or Feather Rivers.

DFG Exhibit #15

The Status of San Joaquin Drainage Chinook Salmon Stocks, Habitat Conditions and Natural Production Factors

California Department of Fish and Game
Region 4
Fresno, California

July, 1987

Prepared for the State Water Resources Control Board Bay/Delta Hearing Process PHASE I: Determination of Beneficial Uses and Determination of Reasonable Levels of Protection. September, 1987

We analyzed the relationship between San Joaquin River flows at Vernalis and March, April and May water temperatures from 1965 to 1984 in conjunction with the chronic temperature stress levels (Rich, 1987) for San Joaquin smolts entering the Delta. The USGS temperature records at Vernalis were reported in different ways so the summary required different treatments. Mean monthly temperatures for the period 1964-1969 were used as published. The mid-point (median) was used when maximum-minimum temperature ranges were provided (1974-1984).

We found no correlation between streamflow and water temperature in March or April. A significant ($p < 0.01$; $r = 0.60$) curvilinear relationship was found in May under the streamflow and weather conditions existing 1965-1984 (Figure 9). Using this relationship and overlaying the chronic temperature stress criteria we found that at Vernalis flows of 5,000 cfs or less in May, chinook smolts entering the Delta are subjected to high chronic temperature stress (Figure 9). In looking at the actual temperature data for all May periods corresponding with Vernalis flows less than 5,000 cfs, in 8 of 13 years the water temperatures were in fact in the high stress range. The years 1971 and 1976 were also very close to the high chronic stress temperature of 67.6°F (19.7°C).

BH

A MODEL FOR ESTIMATING MORTALITY AND SURVIVAL OF FALL-RUN CHINOOK SALMON SMOLTS IN THE SACRAMENTO RIVER DELTA BETWEEN SACRAMENTO AND CHIPPS ISLAND

Martin Kjelson[1], Sheila Greene[2], Pat Brandes[1]

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WQCP-USFWS-1

ABSTRACT

A multiple regression model is described that predicts fall-run chinook salmon smolt survival through the Sacramento River Delta between Sacramento and Chipps Island (near Pittsburg, CA). The model uses water temperature at Freeport, CA, the fraction of water diverted from the Sacramento River at Walnut Grove, CA, and total exports of the State Water and Central Valley Projects in the south delta. Each of these three factors is negatively related to smolt survival. Survival indices were based on coded wire tagged (CWT) smolts released at several delta sites and subsequently recovered at Chipps Island. CWT smolts were released under various environmental conditions. Correlation and regression analyses were used to choose those factors that explained a significant part ($p=0.95$) of the variation in smolt mortality. The model predicts the survival of smolts migrating from Sacramento to Chipps Island via the Sacramento River, and through the central delta via the Mokelumne and lower San Joaquin River systems. The greatest mortality was observed for smolts diverted into the central delta, indicating that keeping smolts out of that region would be highly beneficial to salmon production. Simulations of survival under varying temperature, fractions diverted and exports are provided to quantify the benfits of alternative salmon protective measures.

A Model for Estimating Mortality and Survival of Fall-Run Chinook Salmon Smolts in the Sacramento River Delta between Sacramento and Chipps Island

by M. Kjelson, S. Greene and P. Brandes

INTRODUCTION

During Phase I of the California State Water Resources Control Board (CSWRCB) Bay/Delta Proceedings of 1987, the United States Fish and Wildlife Service (USFWS) presented testimony which described the relationships between survival of salmon smolts and streamflow, diversions and water temperature as smolts migrate downstream from Sacramento to Chipps Island (Figure 1). The relationship between survival and flow was used to represent the response of smolts to changes in flow, water temperature and diversion.

The USFWS noted that they had been unable to separate the independent effects of these three factors, but noted that smolt survival increased with increased river flows, decreases in the fraction diverted off the Sacramento River at Walnut Grove, and decreased water temperatures.

The inability to separate the effects of these physical factors was due to the fact that experimental coded wire tagged (CWT) smolts had most frequently been released at high water temperatures, high diversion fractions and low flows, or at low water temperatures, low diversion fractions and high flows. These two sets of conditions reflect how the State Water Project (SWP) and Central Valley Project (CVP) have operated in recent years, and the fact

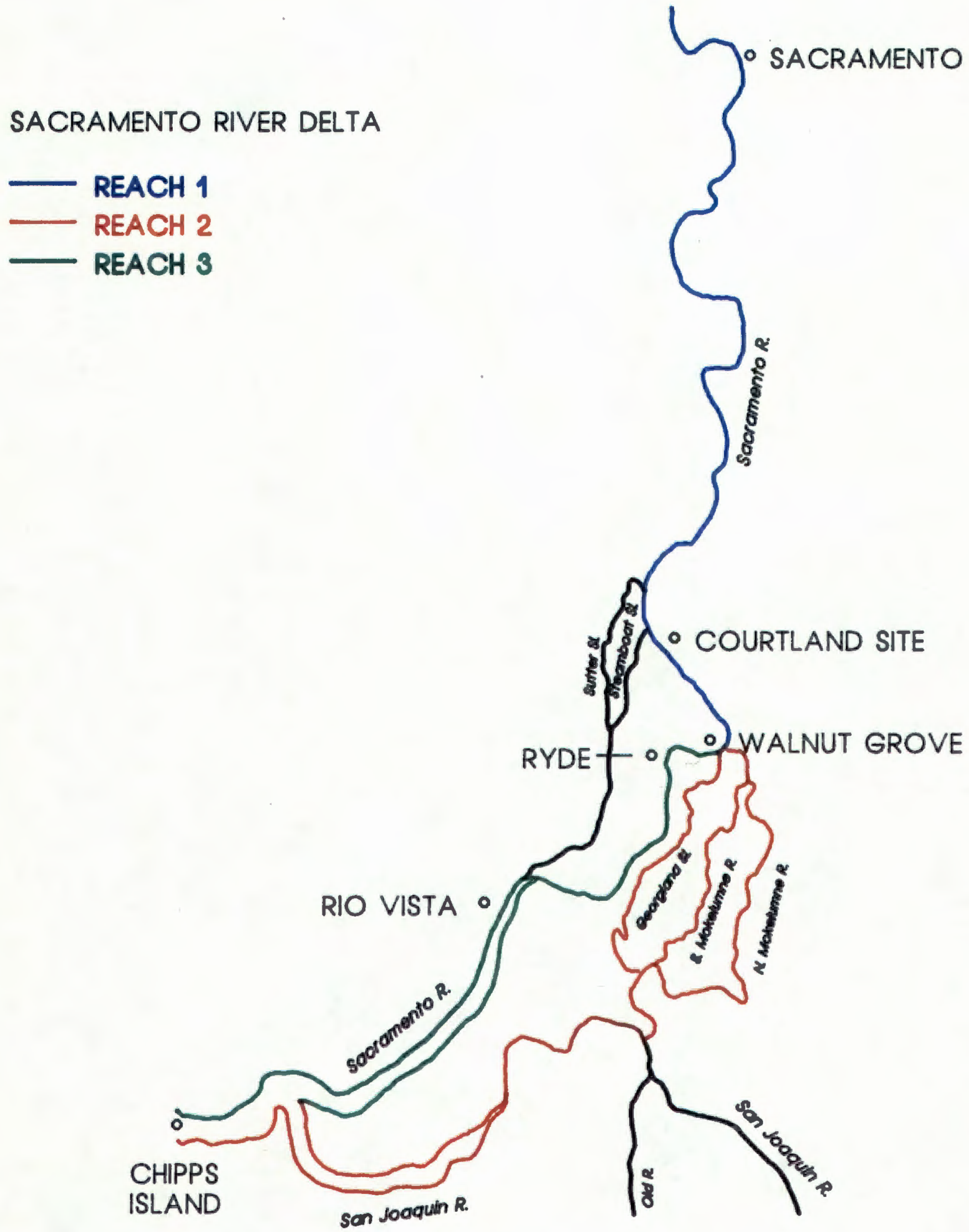


Figure 1. Reach diagram for Delta Survival Model.

that water temperatures naturally increase as flows decrease as the spring progresses. Survival was not measured when both flows and temperatures were low, when lower temperatures could have increased survival. The above conditions resulted in the three physical factors being intercorrelated (termed colinearity). Hence, as noted in our 1987 testimony, survival may have been underestimated during cooler, low flow periods using the flow:survival relationship.

During the spring of 1988 and 1989, management of the delta and upstream reservoir system allowed us to estimate the effects of the three factors independently. In these years CWT smolts were released in early May at relatively low flows and low temperatures and in June at low flows and higher temperatures. Diversion fractions were both high and low during both the May and June releases in 1988. These additional data enabled us to better separate the effects of flow, diversion and water temperature, and to develop a model that quantifies the smolt survival response to changes in several environmental parameters in the Sacramento River Delta.

The data used to develop the model has some limitations. (1) Survival measurements were not made over a broad range of conditions, (2) sample variability or potential error is present in both sample and environmental measurements, (3) some colinearity remains between factors, (4) there is a lack of survival measurements for specific reaches in the delta.

We have developed a multiple regression model that relies on the use of those environmental variables that account for a statistically significant fraction of the variation in survival. The model is conservative in that the environmental variables chosen were individually significant in each equation at the 95% level, and each regression equation was significant at 95%. This approach, along with the data limitations described, may have prevented us from including certain factors at this time in the model that influence smolt survival. Further analysis with additional data may allow us to improve the model in the future.

Our goal was to develop a model that explains a large degree of the variation in observed survival, that uses factors which are statistically significant in the equation, and appears ecologically sound. The model will be used to help quantify the benefits of varied salmon protective measures in the Sacramento River portion of the delta.

The purpose of this report is to summarize the methods used to develop the smolt survival model, describe the model, present model simulations that help quantify the relative benefits of decreased water temperature and varied operational measures.

This report reflects efforts and review comments by members, staff and consultants of the Delta Salmon Team under the Five Agency Salmon Management Group. The Five Agency Group was established to evaluate relative benefits and costs of both operational and structural protective measures to improve salmon production in the Central Valley and Bay/Delta Estuary. Primary support and guidance is through the Fisheries/Water Quality Committee of the Interagency Ecological Study Program.

ACKNOWLEDGEMENTS

We would like to thank Dave Dettman, who initiated this modeling effort and developed the first version; and Steve Cramer, who reviewed the model and suggested important physical restructuring of the model. We are grateful to Randy Brown, Pat Coulston, Chuck Hanson, Don Kelley, Wim Kimmerer, William Mitchell, and Don Stevens for reviewing the model and offering important criticism and advise. Appreciation is also extended to the SWP and CVP operations staffs for their assistance in helping provide experimental hydraulic conditions, to the many field personnel that assisted in tagging, sampling and CWT reading, and to the personnel at Feather River Hatchery for providing smolts for our studies.

METHODS

Sources of Smolt Survival and Mortality Indices

Survival indices were based entirely on trawl recoveries at Chipps Island from the years 1978 through 1989 (USFWS, 1987). All indices were adjusted by dividing by 1.8 to bring those indices greater than 1 into the range of 0 to 1, in order to maintain biologically meaningful survival rates. This adjustment procedure assumes consistent, not skewed, error in the raw survival rates. To support the adjustment an examination of the frequency distribution plot of the survival indices indicated an approximately normal distribution with a median near 1.0 and a maximum near 1.8. Adjusted survivals were converted to adjusted mortalities by subtracting from 1.0.

Sources of Environmental and Physical Data

Flow estimates, delta exports for the SWP and CVP were obtained from the California Department of Water Resources (CDWR) - Central District DAYFLOW model. Temperature data were obtained from the United States Geological Survey (USGS) or CDWR continuous recorders, and CDFG and USFWS grab-samples taken at the time of CWT releases. Fish sizes, defined as the number smolts per pound smolts (smaller values indicate a larger mean size of individual smolts), were obtained from CDFG and USFWS hatchery truck planting receipts. Tide phase at Martinez was estimated using a USGS tide predictor program, modified by CDWR, and National Oceanographic and Atmospheric Administration (NOAA) records. The effect of tide velocity at Walnut Grove was estimated by lagging the tide phase at Martinez three hours. The tide velocity effect was assigned a value between 1 (estimated strongest ebb) to 8 (estimated strongest flood) to facilitate regression analysis.

Estimating Mortality in each of Three Reaches

The Sacramento River portion of the delta was divided into three reaches. Reach 1 extended from Sacramento to Walnut Grove; Reach 2, from Walnut Grove to Chipps Island, via the Mokelumne and lower San Joaquin River systems (the central delta); Reach 3, from Walnut Grove to Chipps Island, via the Sacramento River system below Walnut Grove (Figure 1).

Using equations described below, mortality in each reach was estimated from mortality indices of CWT smolts released at Sacramento, just below the mouth of Steamboat Slough ("Courtland" site), and at Ryde (Figure 1). The mortality indices of CWT smolts released at Sacramento represent M_T, the total mortality from Sacramento to Chipps Island. The mortality indices of CWT smolts released at the "Courtland" site represent M_{23}, the combined mortality in Reaches 2 and 3; and the mortality indices of CWT smolts released at Ryde represent M_3, mortality in Reach 3.

Mortality in Reach 1 was treated sequentially with the mortality below Reach 1, the combined mortality in Reaches 2 and 3. In our model, smolts which survived in Reach 1 were subsequently subjected to mortality in either Reaches 2 or 3, depending in their migration route.

Ricker (1975) developed an approach to describe the combined effect of two independent sources of mortality (e.g. fishing and natural). We adapted Ricker's approach to mortality occuring sequentially over two distinct time periods in order to apply it to the population of smolts migrating first through Reach 1 and second through Reaches 2 or 3. Ricker's equation states that the combined mortality due to two separate sources equals the sums of the mortalities minus the product of the mortalities, or

$$M_T = M_a + M_b - (M_a * M_b).$$

Applying this equation to the Sacramento River portion of the delta, we get,

$$M_T = M_1 + M_{23} - (M_1 * M_{23}), \qquad \text{Eq. 1}$$

where M_T = total mortality from Sacramento to Chipps Island, M_1 = mortality from Sacramento to Walnut Grove, and M_{23} = combined mortality in Reaches 2 and 3, the central delta and the Sacramento River below Walnut Grove to Chipps Island. Since M_T and M_{23} were measured, we solved Eq. 1 for M_1 to get

$$M_T = M_{23} + [(M_1 * (1 - M_{23})]$$

$$M_T - M_{23} = M_1 * (1 - M_{23})$$

$$M_1 = (M_T - M_{23}) / (1 - M_{23}) \qquad \text{Eq. 2}$$

We assumed negligible mortality from the "Courtland" site to Walnut Grove, a distance of about 3.5 miles.

Mortality in Reach 2, the central delta, was treated in parallel, and isolated from mortality in Reach 3, the Sacramento River below Walnut Grove to Chipps Island. At the downstream boundary of Reach 1, the proportion of the smolts entering Reach 2 was defined by the fraction of the Sacramento River flow diverted into the central delta via the Delta Cross Channel and Georgiana Slough. The proportion of smolts entering Reach 3 is defined by the fraction of Sacramento River flow remaining in the Sacramento River below Walnut Grove. The fraction diverted was not included as an independent variable in the regression analyses, because it entered the model mechanistically, but still influenced the predicted survival through the delta by determining the porportion of smolts diverted into the central delta. In previous versions of the model, the fraction diverted was the most highly correlated parameter with the mortality, M_{23}, of CWT smolts released at the "Courtland" site ($r = 0.54$).

Applying a proportionality equation to the Sacramento River portion of the delta below Walnut Grove, we get

$$M_{23} = M_2*P_2 + M_3*P_3, \qquad \text{Eq. 3}$$

where M_2 = mortality from Walnut Grove to Chipps Island via the central delta, P_2 = proportion of Sacramento River flow diverted in the central delta, M_3 = mortality from Walnut Grove to Chipps Island via the Sacramento River, and P_3 = proportion of Sacramento River flow remaining in the Sacramento River below Walnut Grove. Since M_{23} and M_3 were measured, we solved Equation 3 for M_2 to get

$$M_2*P_2 = M_{23} - M_3*P_3$$

$$M_2 = (M_{23} - M_3*P_3) / P_2 \qquad \text{Eq. 4}$$

Mortality in Reach 3, the Sacramento River below Walnut Grove to Chipps Island, was treated in parallel, and isolated from, mortality in Reach 2. M_3 was measured directly, therefore no computations were involved.

We assumed negligible mortality between Walnut Grove and Ryde, a distance of about 3 miles.

In cases where the application of our equations to isolate the estimated mortality in Reaches 1 and 2 produced mortality values less than 0 or greater than 1, mortality was truncated to 0.0 and 1.0 respectively. We truncated estimated mortalities to maintain biologically meaningful mortality values, and to remain consistent with the subsequent use of this model in a Salmon Population Model (Mitchell, 1989). We were aware that truncating reduced the variation in the non-truncated data.

Migration Rate/Time Intervals

We estimated the migration rates and time intervals, in days, of CWT smolts as they emigrated through each of the three reaches. The migration rates enabled us to calculate how long the smolts were exposed to the environmental conditions in a specific reach during a specific time interval. The minimum and maximum migration rates of CWT smolts released at Ryde were estimated by dividing the total distance of Reach 3 by the time interval between smolt release at Ryde and recapture at Chipps Island. Assuming smolts migrated at the same rate throughout Reach 3, the minimum and maximum migration time intervals in several subsections of Reach 3 were calculated by multiplying the minimum and maximum migration rates by the subsection distance.

The minimum and maximum migration time intervals in Reach 2 using CWT smolts released at the "Courtland" site were determined by the time intervals between smolt release at the "Courtland" site and recapture at Chipps Island. We realized this approach may have underestimated the minimum migration time interval in Reach 2 because some of the smolts released at the "Courtland" site migrated via the Sacramento River, considered a shorter migration route.

The migration time intervals in Reach 1 using CWT smolts released at Sacramento from 1978 to 1982 were based on existing information on smolt migration and estimated water velocity through Reach 1. For detailed discussion, refer to Dettman, 1989.

By estimating the migration time interval and dates of smolts in a given reach we estimated the environmental conditions to which they were exposed (Appendix 2). To provide the reader with a general knowledge of migration time intervals for smolts passing from Sacramento to Chipps Island, we developed the following :

REACH	TIME PERIOD
Sacramento to Walnut Grove	Two days
Walnut Grove to Chipps Island via the central delta	Ten days
Walnut Grove to Chipps Island via the Sacramento River	Seven days
Sacramento to Chipps Island	Twelve days

Correlation and Regression

We compared our mortality estimates to the environmental conditions at the time the fish were migrating using correlation and interactive multiple linear regression techniques to determine how the varied environmental parameters affected mortality by reach (Snedecor and Cochran, 1967). These analyses justified our selection of the environmental parameters used in the model.

We analyzed correlations between smolt mortality and several flow parameters, export rates and water temperatures as marked smolts pass through the Sacramento River portion of the delta. We also evaluated the potential influence of smolt size and tide phase at the time of release to assess how variation in these experimental conditions might effect survival. Neither size nor tide phase were considered as a model parameter since they were not factors that could be managed for increased smolt survival.

We performed multiple linear regression analyses between estimated smolt mortality and the individual factors described above for each of the three reaches. Whereas correlation analysis allowed us to examine the relationships between mortality and individual parameters, multiple regression analysis enabled us to evaluate the effects of multiple factors in combination with each other on mortality. F-test values were used to determine the order in which factors were incorporated into the regression equation. An additional factor was incorporated only if the combination of parameters yielded a better r-squared value and a significant F-test value, and all factors were individually significant in the regression equation at 95% based on their t-statistic. Only those parameters whose t-test values were significant at 95% or greater were included in the regression equation.

RESULTS AND DISCUSSION

Estimated Mortality in Reach 3 (Walnut Grove to Chipps Island)

We used our survival indices from smolts releases at Ryde to estimate the mortality in Reach 3. These data were obtained from 1983 through 1989 (Table 1, Appendix 1). Releases were made with the Delta Cross Channel gates both open and closed. Adjusted mortalitites averaged 0.56 and ranged from 0.29 to 0.91.

Environmental Influences in Reach 3

We correlated estimated mortality in Reach 3 to a variety of factors that appeared to have an ecological basis to influence smolt mortality in that reach (Table 2).

A significant positive correlation was found between mortality and both instantaneous water temperature at release site and average daily water temperature at Freeport (Table 2). Water temperature affects smolts both directly through acute (lethal) effects and indirectly through chronic (sublethal) effects. Laboratory experiments have demonstrated that juvenile chinook salmon all die at about 78°F (Brett, 1952). Chronic temperature effects are more difficult to quantify, but are those related to physiological stress, predator and smolt metabolic demands, disease, growth, and other factors whose effects on smolt survival have been shown to increase with a rise in temperature (Hanson, 1989).

There has been some concern that the linear nature of the temperature:mortality relationship depicted in Figure 2 may be unrealistic due

Table 1. Trawl survival indexes, mortality indexes (M_3) and environmental data for CWT chinook salmon smolts released at Ryde from 1983 through 1989.

CWT Number	Release Year	Trawl Surv Index	Adjusted Mort, M_3	Inst Water Temp °F a Release Site (Ryde)	Average Daily Water Temp °F a Freeport On Release Date	Mean Daily Flows (CFS) at: Freeport (QSAC)[1]	Rio Vista (QRIO)[2]	Jersey Pt QWEST)[3]	Chipps Is (QOUT)[4]	Daily SWP+CVP Exports cfs[5]	Size, No Smolts per Pound Smolts	Tide Phase Index
66223	1983	1.18	0.34	61	62.5	52400	42989	35026	77042	4150	77	5
66229	1984	1.05	0.42	66	68.8	13900	6395	1108	8083	5497	88	3
66235	1985	0.77	0.57	66	61.3	14000	7051	-147	6898	6690	78	5
66248	1986	0.68	0.62	74	72.0	13700	6870	6964	13439	5612	85	5
66255	1987	0.85	0.53	67	67.4	11600	6451	1046	5619	5524	76	3
66258	1987	0.88	0.51	64	67.5	10900	5046	511	4387	5147	73	1
63101	1988	0.94	0.48	63	63.9	7970	6029	285	8032	7025	54	3
63102	1988	1.28	0.29	61	59.9	12100	7322	-271	8146	7959	53	1
66263	1988	0.40	0.78	75	73.4	11100	7357	-2569	3117	6500	55	6
63103	1988	0.34	0.81	74	72.9	13400	5588	-1736	2491	6253	52	8
63112	1989	1.19	0.34	62	62.1	11178	4280	-247	7594	3942	64.8	3
63107	1989	0.46	0.73	67	68.7	13151	7647	-1563	7673	5373	48	3
H6114102	1989	0.16	0.91	73	70.0	14036	7709	-1243	5702	4709	57.9	8

1 - Mean of the mean daily Sacramento River flows at Freeport on the day(s) smots were released at Ryde.
2 - Mean of the mean daily Sacramento River flows at Rio Vista on the day(s) smolts passed Rio Vista.
3 - Mean of the mean daily San Joaquin River flows at Jersey Point on the day(s) smolts passed Chipps Island.
4 - Mean of the mean daily Net Delta Outflows on the day(s) smolts passed Chipps Island.
5 - Mean of the daily SWP plus CVP exports during the period smolts passed from release point to Chipps Island.

Table 2. Correlation coefficients between estimated mortality using CWT chinook salmon smolts released in the Sacramento River at Ryde and recovered at Chipps Island (M_3), and selected environmental variables. Symbols: **, correlation significant at the 0.01 level.

	Inst Water Temp °F @ Release Site (Ryde)	Average Daily Water Temp °F @ Freeport on Release Date	-----------Mean Daily Flow (CFS) at:----------- Freeport (QSAC)[1]	Rio Vista (QRIO)[2]	Jersey Pt (QWEST)[3]	Chipps Is (QOUT)[4]	Daily SWP+CVP Exports cfs[5]	No Smolts per Pound Smolts	Tide Phase Index
Correlation Coefficients (r)	0.87**	0.81**	-0.29	-0.30	-0.39	-0.39	0.00	-0.37	0.74**

[1] - Mean of the mean daily Sacramento River flows at Freeport on the day(s) smolts were released at Ryde.
[2] - Mean of the mean daily Sacramento River flows at Rio Vista on the days(s) smolts passed Rio Vista.
[3] - Mean of the mean daily San Joaquin River flows at Jersey Point on the days(s) smolts passed Chipps Island.
[4] - Mean of the mean daily Net Delta Outflow on the days(s) smolts passed Chipps Island.
[5] - Mean of the daily SWP plus CVP exports on the day(s) smolts pass from release point to Chipps Island.

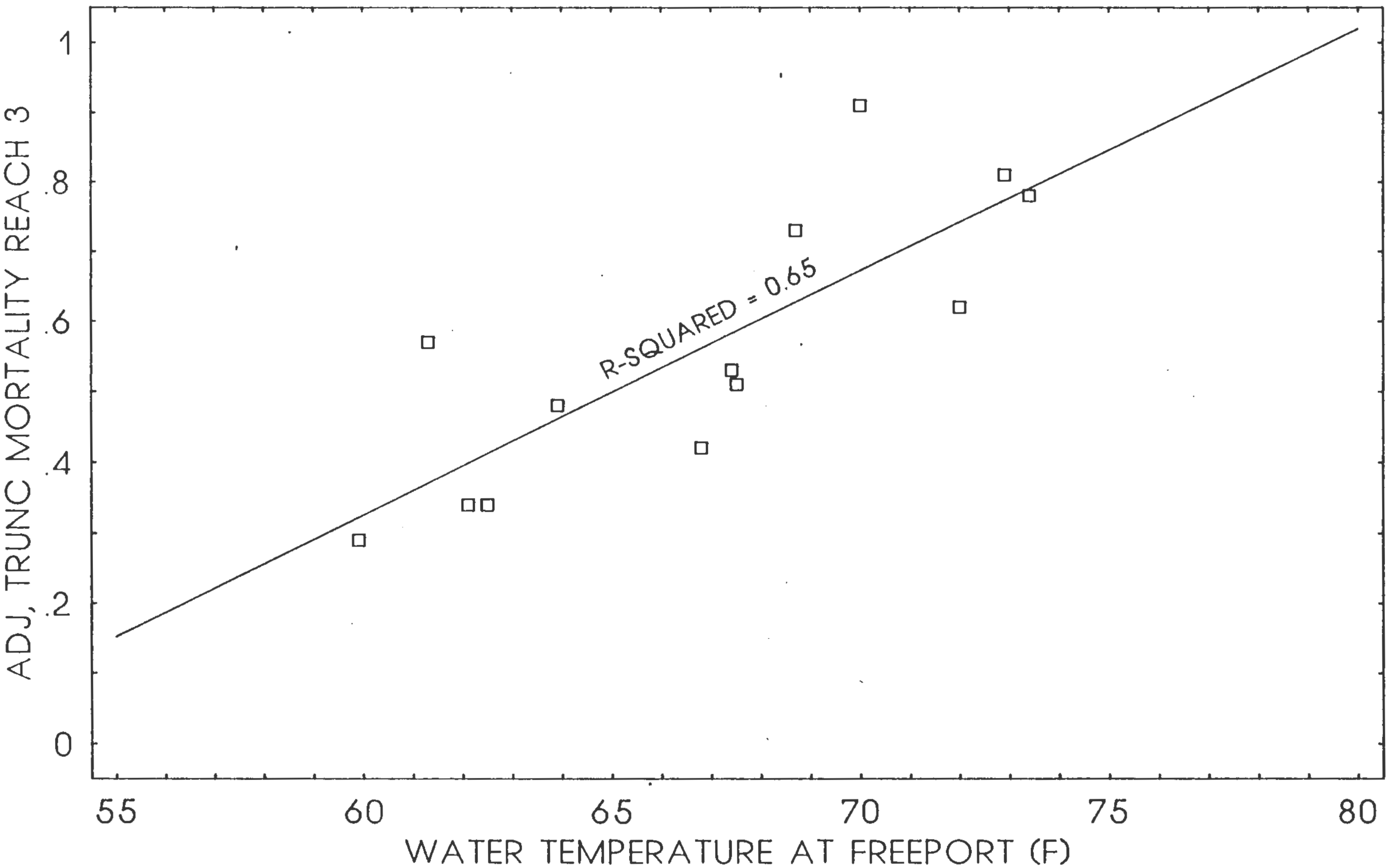


FIGURE 2. ESTIMATED CHINOOK SALMON SMOLT MORTALITY
VERSUS AVERAGE DAILY WATER TEMPERATURE
AT FREEPORT ON RELEASE DAY, REACH 3

to potential biases associated with the use of CWT hatchery smolts, and the belief that the chronic (sublethal) temperature effects described above are unlikely to have much influence on survival at the lower temperatures (~60 to 63°F). We have not answered these concerns fully and uncertainty remains. For instance, there is limited data to suggest that the survival of naturally produced smolts also is negatively correlated with temperature in a linear manner, and there is also other CWT data not used in modeling that indicates survival can be relatively high at high temperatures. Refer to discussion in Hanson, 1989 and USFWS, 1989.

The only other significant correlation was between estimated mortality in Reach 3 and the tide phase index (Table 2.). Smolts released at Ryde on a flood tide may be carried upstream and into the Delta Cross Channel and Georgiana Slough and therefore exposed to mortality in Reach 2. This suggests that our estimate of mortality in Reach 3 may be biased high for releases made when the tide was flooding.

There was no significant correlation between mortality and flow. It has been hypothesized that increased flows would reduce smolt mortality through increased migration rate, and thus lessened exposure times to any adverse conditions. We have not, however, demonstrated a correlation between smolt migration rate and flow in the delta presumably due to the complexity of smolt migration behavior in tidal waters. Higher flow could provide dilution of contaminants, and is typically accompanied by higher turbidity which may reduce smolt mortalities caused by sight feeding predators.

The lack of a significant correlation with exports is not unexpected since smolts released at Ryde, while vulnerable to diversion into the lower

San Joaquin via Threemile Slough, are less likely to be carried into the southern delta than, for instance, smolts released at the "Courtland" site.

The negative correlation between estimated smolt mortality and the number of smolts per pound was opposite to what we expected and suggests mortality decreases as smolt size decreases. It is counter to population biology and data from fry, smolt and yearling CWT releases that indicate mortality typically increases as size decreases. It has been hypothesized that net avoidance by the larger CWT smolts may have caused the above relationship between size and mortality. However, for the relatively narrow range of smolt sizes we used and the high turbidity seen at Chipps Island which should hinder avoidance by smolts of all sizes, we doubt that the net avoidance hypothesis is supportable. Thus, we believe the correlation is spurious.

Our interactive multiple regression analysis indicated that average daily temperature at Freeport on release day by itself accounted for 65% of the variation in smolt mortality in Reach 3 (Table 3). We chose water temperature at Freeport, rather than at the release site, since we have an historic record of water temperature at Freeport and it is highly correlated with the temperature at Ryde ($r = 0.94$).

Tide phase index was the only other parameter individually significant at 95%. By itself, it explained 54% of the variation, however, incorporating it into the equation with water temperature severely reduced the significance of both coefficients in the equation based on the t-statistic. In other words, tide phase did not account for a significant portion of the residual variation in mortality after the mortality due to water temperature was removed. Our tide phase index was crude and it is not surprising that it

Table 3. Linear regression between estimated mortality using CWT chinook salmon smolts released in the Sacramento River at Ryde and recovered at Chipps Island (M_3) and average daily water temperature at Freeport on release day.

Variable	Regression Coefficient	Standard Error	T-Statistic	Partial Correlation	Cumulative Percent Variation Explained
Intercept	-1.766	0.5136	-3.440	----	----
Average Daily Water Temp °F @ Freeport on Release Day	0.03489	0.007672	4.547	0.81	65.3

R-Squared = 0.6527
F-test: F ratio = 20.68
Standard error or regression = 0.1211

reduced significance in the equation. We are still interested in designing a better estimate of tide influence at release site.

The equation predicting smolt mortality through Reach 3 is as follows :

$M_3 = -1.766 + (0.03489 * \text{ave water temperature °F at Freeport, CA})$

<u>Mortality in Reach 2 (Walnut Grove to Chipps Island via the central delta)</u>

Table 4 lists estimates of M_2 for each release made at the "Courtland" site since 1983. Adjusted mortalities in Reach 2 are the highest of all three reaches, averaging 0.85 and ranging from 0.63 to 1.00 (Table 4, Appendix 1).

<u>Environmental Influences in Reach 2</u>

We correlated the estimated mortality in Reach 2 to the factors listed in Table 4. The environmental factors chosen for Reach 2 analyses were those believed most applicable to that reach, hence flow in the Sacramento River, used on Reach 3 analysis, was omitted.

Our water temperature parameter used in Reach 2 was, again, measured at Freeport due to the availability of historic data and the fact that there was a reasonable correlation between water temperature at Freeport and the "Courtland" site ($r = 0.97$), and between water temperature at Freeport and in the Mokelumne River system ($r = 0.92$). Temperature data for the delta portion of the Mokelumne River were only available for the spring of 1989.

Results of our correlation analysis (Table 5) indicated mortality in Reach 2 was positively correlated to water temperature at Freeport ($r = 0.73$, $p = 0.99$) and water temperature at the release site. Weaker negative correlations were seen between mortality and net delta outflow (QOUT) at Chipps Island ($r = -0.53$, $p = 0.90$) and flow at Jersey Point (QWEST) (r =

TABLE 4. Trawl mortality indexes (M_2) and environmental data using CWT chinook salmon smolts released at the "Courtland" site from 1984 through 1989.

CWT Number	Release Year	Trawl Surv Index	Adjusted Truncated Mort, M_2	Inst Water Temp °F @ Release Site (Walnut Grove)	Average Daily Water Temp °F @ Freeport on Release Date	Mean Daily Flows (CFS) at: Jersey Pt (QWEST)[1]	Mean Daily Flows (CFS) at: Chipps Is (QOUT)[2]	Daily SWP+CVP Exports cfs[3]	Size, No Smolts per Pound Smolts	Tide Phase Index
66224	1983	1.06	0.65	60	60.1	35241	77531	3730	87	1
66227	1984	0.61	0.81	66	65.5	1085	8051	5596	74	8
66238/41	1985	0.34	0.94	64	61.3	-60	6727	6517	78	1
66243	1986	0.35	0.92	73	71.6	6923	13401	5281	80	1
66253/4	1987	0.67	0.77	66.5	67.3	889	5698	5616	74	3
66256/7	1987	0.40	1.00	66.5	67.5	558	4816	5436	71	1
B61402/3	1988	0.70	0.81	62	63.5	-2361	6364	7497	61	3
B61404/5	1988	0.76	0.82	61	62.1	-2957	5854	8020	64.5	1
66259/60	1988	0.17	1.00	73	72.0	-2569	3117	6454	57	5
66250	1988	0.02	1.00	76	74.3	-1477	2423	6094	59	8
63111	1989	0.84	0.63	60.5	60.8	-299	7578	4224	60.7	8
63108	1989	0.35	0.84	69	68.7	-2581	8140	4919	44	3
65805/3	1989	0.21	0.87	71	70.9	-1262	6698	4568	54.1	8

[1] - Mean of the mean daily San Joaquin River flows at Jersey Point on the days(s) smolts passed Chipps Island.
[2] - Mean of the mean daily Net Delta Outflows on the days(s) smolts passed Chipps Island.
[3] - Mean of the daily SWP plus CVP exports on the days(s) smolts passed from release point to Chipps Island.

Table 5. Correlation coefficients between estimated mortality using CWT chinook salmon smolts released at "Courtland" site and recovered at Chipps Island for Reach 2, Walnut Grove to Chipps Island via the central delta, (M_2) and selected environmental variables. Symbols : **, correlation significant at 99% level, correlation significant at 95% level.

	Inst Water Temp °F @ Release Site (Walnut Grove)	Average Daily Water Temp °F @ Freeport On Release Date	Mean Daily Flow (CFS) at:		Daily SWP+CVP Exports cfs3	No Smolts per Pound Smolts	Tide Phase Index
			Jersey Pt (QWEST)1	Chipps Is (QOUT)2			
Correlation Coefficients (r)	0.73**	0.69**	-0.47	-0.53*	0.41	-0.19	-0.07

[1] - Mean of the mean daily San Joaquin River flows at Jersey Point on the day(s) smolts passed Chipps Island.
[2] - Mean of the mean daily Net Delta Outflow on the day(s) smolts passed Chipps Island.
[3] - Mean of the SWP plus CVP exports on the day(s) smolts passed from release point to Chipps Island.

-0.47, p = 0.90). The net delta outflow correlation probably reflects colinearlity with water temperature. As outflow increases we typically see a decrease in water temperature at the same time. We believe reverse (negative) flows at Jersey Point in the lower San Joaquin (QWEST) may increase smolt mortality, again, by increasing exposure times, or causing the smolts to migrate toward the southern delta pumping plants rather than toward the ocean. It is probable that the DAYFLOW estimates of net flow at Jersey Point in the western San Joaquin River are somewhat inaccurate due to the lack of appropriate tidal influence in the calculation of that flow parameter which could lessen our ability to demonstrate a correlation between mortality and QWEST should one exist.

Multiple regression analysis indicated that the combination of water temperature at Freeport and total SWP plus CVP exports explained 66% of the variation in mortality in Reach 2 (Table 6). Temperature alone explained 48% of the variation, and exports alone explained 17% of the variation. Combining water temperature and exports increased the significance of both water temperature and exports regression coefficients (t-statistic) to 99.5% and 95%, respectively and increased r-squared to 66% (Appendix 3). The mortality as related to water temperature is shown in Figure 3, and the residual mortality (that remaining after the mortality explained by water temperature alone is removed) as related to total exports is shown in Figure 4.

Total exports is considered an index parameter to reflect the influence of drawing water and smolts toward the southern delta pumping plants from the central delta. Mortalities were greater for CWT smolts released in the lower portion of Old River in the southern delta when compared to those released in the central and northern delta (USFWS, 1987). Higher smolt mortality in the

Table 6. Stepwise multiple linear regression between estimated mortality using CWT chinook salmon smolts released at "Courtland" site and recovered at Chipps Island for Reach 2, Walnut Grove to Chipps Island via the central delta, (M_2) and average daily water temperature at Freeport on the day of release, daily State Water Project plus Central Valley Project exports during the period smolts passed from release point to Chipps Island.

Variable	Regression Coefficient	Standard Error	T-Statistic	Partial Correlation	Cumulative Percent Variation Explained
Intercept	-0.5808532	0.3343113	-1.737462	----	----
Average Daily Water Temp °F @ Freeport on Release Day	0.0179269	0.0047439	3.778932	0.77	48.71
SWP plus CVP Exports	0.0000418	0.0000184	2.279014	0.58	66.43

R-Squared = 0.6589
F-test = 9.658
Standard error of regression = 0.07834

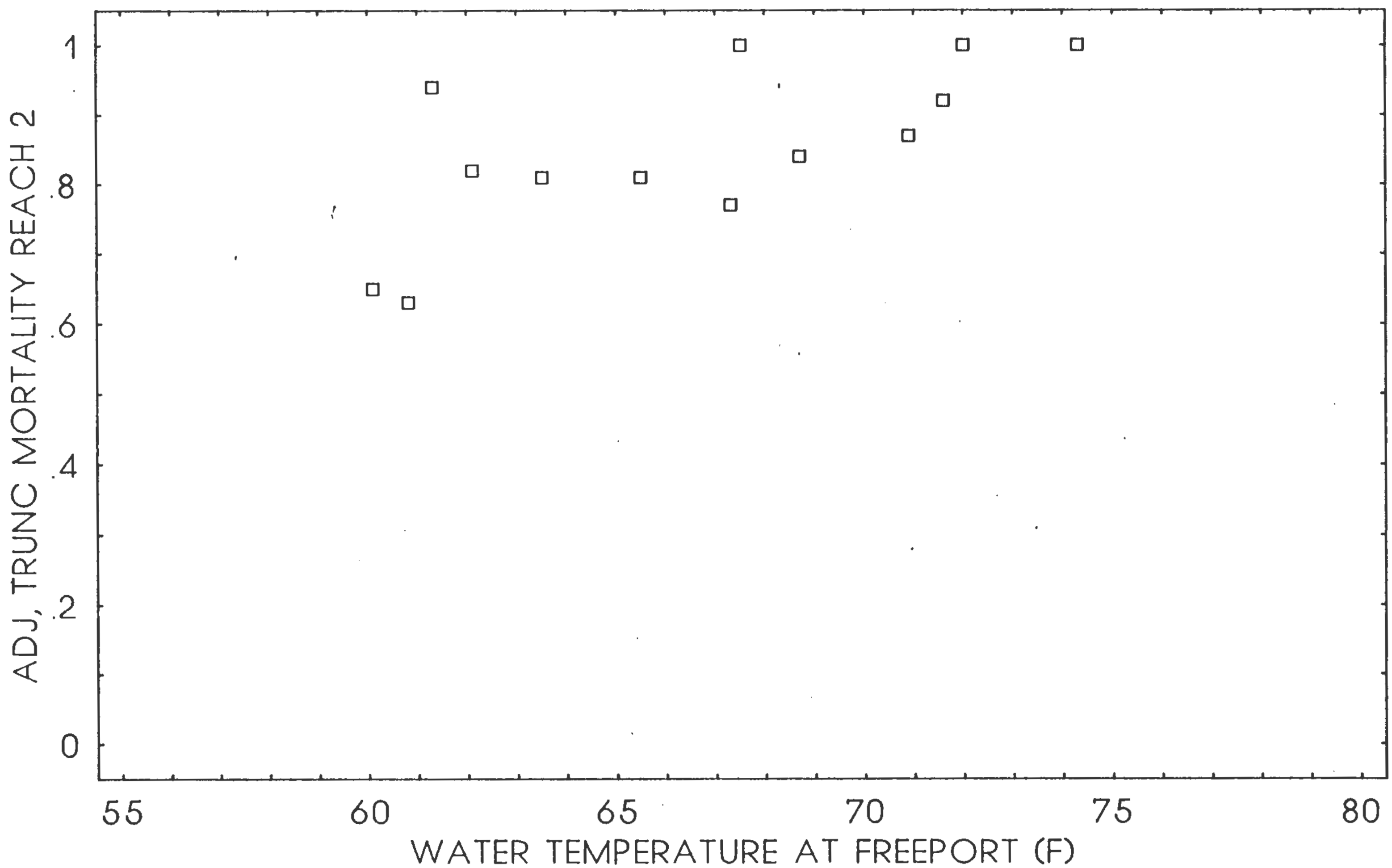


FIGURE 3. ESTIMATED CHINOOK SALMON SMOLT MORTALITY VERSUS AVERAGE DAILY WATER TEMPERATURE AT FREEPORT ON RELEASE DAY, REACH 2

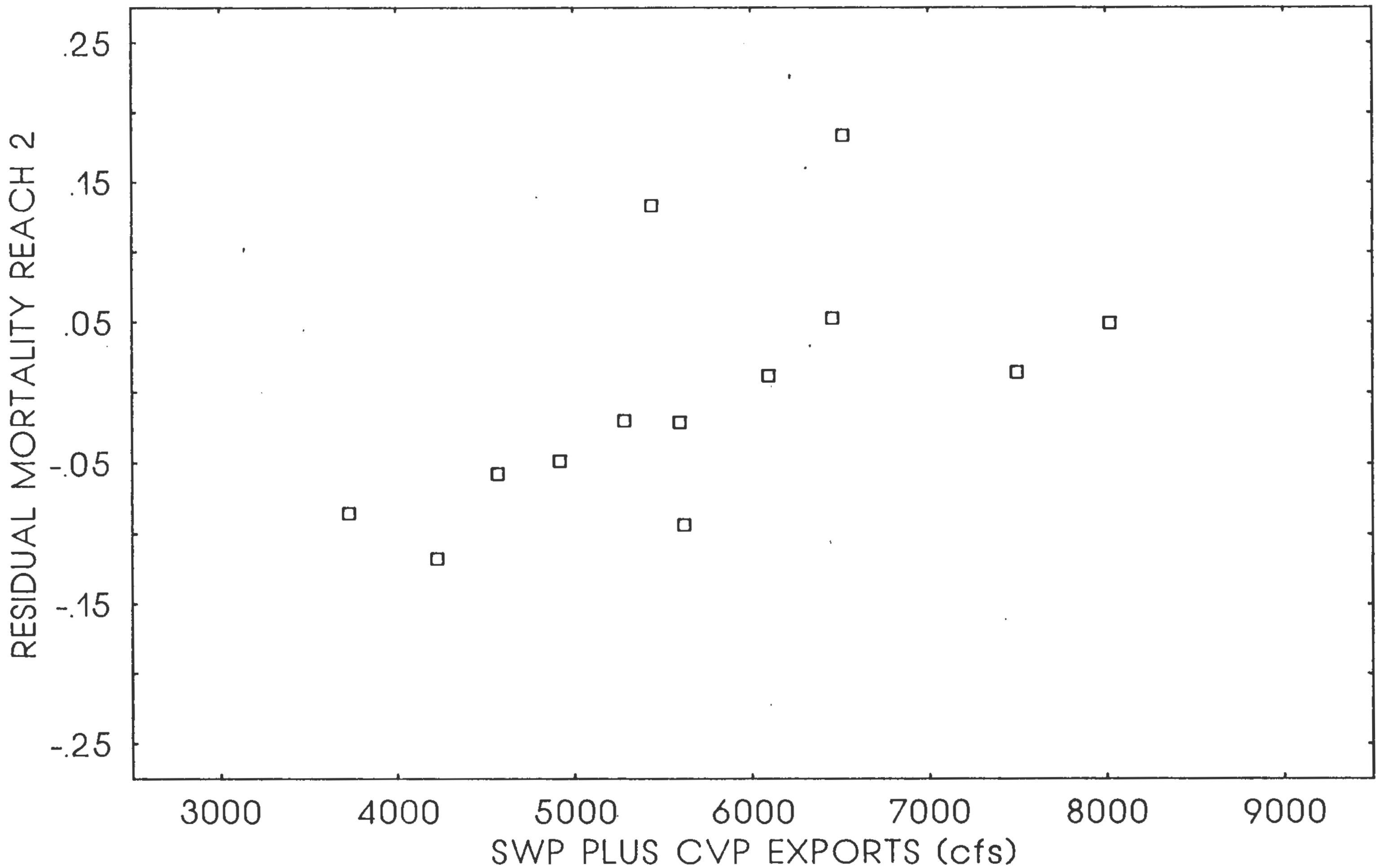


FIGURE 4. RESIDUAL CHINOOK SALMON SMOLT MORTALITY VERSUS AVERAGE DAILY WATER TEMPERATURE AT FREEPORT ON RELEASE DAY, REACH 2

southern delta may reflect the warmer water there than in the Sacramento River, losses of smolts exposed to the intakes of the CVP and SWP, and a longer travel route which increases the chance of loss to predation and other negative factors, such as contaminants.

The combination of water temperature and total exports explained the greatest portion of smolt mortality in Reach 2. It is important to realize that while water temperature and exports explained 66% of the variation in mortality there is still a great deal of mortality at the low temperature of 60°F and relatively low export (~3000 cfs). This indicates that while low temperatures and exports will lessen smolt mortality there are other factors that are not included in the model that influence smolt survival. Further efforts will be made to better define these factors.

The equation used to predict mortality in Reach 2 is :

$$M_2 = -0.5809 + (0.01793 * \text{ave water temp °F at Freeport}) + (0.0000418 * \text{mean SWP plus CVP export pumping rate})$$

Mortality in Reach 1 (Sacramento to Walnut Grove)

One objective of the 1988 and 1989 experiments was to estimate the mortality in Reach 1, using mortality indices from concurrent releases at Sacramento and the "Courtland" site. Equation 2 was used to isolate the mortality in Reach 1,

$$M_1 = (M_T - M_{23}) / (1 - M_{23}) \qquad \text{Eq. 2}$$

This is important because we wanted to know how much of the overall mortality between Sacramento and Chipps Island was due to conditions in Reach 1 alone. Unfortunately, while we did estimate mortality in Reach 1 in 1988 and 1989, there were no concurrent releases below Courtland from 1978 through 1982 from which to estimate mortality in Reach 1. Hence, while mortality estimates based on mortality indices from concurrent releases would have been preferable, reconstructed mortality estimates for Reach 1 were used as described in the next section.

<u>Reconstruction of Mortality Estimates for Reach 1</u>

We reconstructed mortality estimates during years when total survival was measured between Sacramento and Chipps Island. To do this we reconstructed estimated mortality in Reaches 2 and 3 based on the respective regression equations for those two reaches discussed earlier. Then we applied the Ricker's and proportionality equations (Eq. 2 and Eq. 3, respectively) to reconstruct estimated mortality in Reach 1. Beginning with Eq. 2,

$$M_1 = (M_T - M_{23}) / (1 - M_{23}), \qquad \text{Eq. 2}$$

and substituting Eq. 3 for M_{23},

$$M_{23} = M_2*P_2 + M_3*P_3, \qquad \text{Eq. 3}$$

we get,

$$M_1 = [M_T - (M_2*P_2 + M_3*P_3)] / [1 - (M_2*P_2 + M_3*P_3)]$$

$$M_1 = (M_T - M_2*P_2 - M_3*P_3) / (1 - M_2*P_2 - M_3*P_3) \qquad \text{Eq. 5}$$

The data set used to estimate mortality in Reach 1 is provided in Table 7. It is based on:

M_3 as a function of water temperature at Freeport (Table 3).

M_2 as a function of water temperature at Freeport and total SWP and CVP export pumping rates (Table 6).

M_T based on trawl mortality indices, 1978-82 plus 1988 and 1989 (Table 7).

TABLE 7. Trawl survival indexes, mortality indexes and environmental data using CWT chinook salmon smolts released at Sacramento from 1978 through 1982, 1988 and 1989.

CWT Number	Release Year	Trawl Surv Index	Reconst Mort Index (M_1)[1]	Inst Water Temp °F @ Release Site (Sacramento)	Average Daily Water Temp °F @ Freeport On Release Date	--Mean Daily Flow(CFS) at:-- Freeport on Release Date (QSAC)[2]	Freeport - (Sac to Court) (QSAC)[3]	Size No Smolts per Pound Smolts
66202	1978	0.00	1.00	73	69.8	13200	13400	56
66205	1979	0.42	0.00	68	68.8	11980	12650	98
66208	1980	0.32	0.49	62	66.9	13400	13367	61
66211	1980	0.35	0.37	62	66.2	13350	13600	57
66214	1981	0.016	0.94	76	72.4	10650	10170	52
66217	1981	0.00	1.00	76	74.3	9690	9485	55
66220	1982	1.48	0.00	59.5	59.5	45200	44500	95
66218	1982	1.54	0.00	59.4	59.3	43600	42650	71
66221	1982	0.64	0.29	68	62.7	32400	31600	93
B61406/7	1988	0.65	0.00	62	63.5	9670	11123	68
66261/2	1988	0.09	0.17	74	74.3	12000	12800	55
63110	1989	0.18	0.64	67	67.5	13604	13319	54
63115/7	1989	0.21	0.40	69.5	70.0	12748	12748	61.9

1 - Reconstructed mortality reflects adjusted, truncated mortality.
2 - Mean of the mean daily Sacramento River flows at Sacramento on the day(s) smolts were released.
3 - Mean of the mean daily Sacramento River flows at Freeport on the day(s) smolts passed from Sacramento to "Courtland".

Our reconstructed mortalities for Reach 1 ranged from 0.00 to 1.00 and averaged 0.41 (Table 7, Appendix 1). With the exception of 1978 and 1981, estimated mortalities for Reach 1 are quite low.

<u>Structural Limitations in Reach 1</u>

It is important to clarify that our estimates of mortality in Reach 1 were not restricted to the stretch of Sacramento River between Sacramento and Chipps Island. Smolts passing the city of Sacramento can follow not only the Sacramento River but also travel via Sutter and Steamboat Sloughs (Figure 1). The latter sloughs divert about 20 to 30% of the Sacramento River flow which reenters the Sacramento just above Rio Vista. Hence our reconstructed estimates of mortality in Reach 1 are actually the net results of mortality through several potential routes and we assume they represent mortality between Sacramento and Chipps Island not attributable to Reaches 2 and 3. Ideally, Reach 1 should be replaced by several new reaches of the Sacramento River and separate reaches for the two sloughs. We do not have sufficient data to construct such a model. CWT smolts were only released in Steamboat Slough in 1988 and 1989. The raw survival index was 0.38 in 1988 and 0.91 in 1989. The only release made in Sutter Slough was in 1989 the raw survival index was very high (1.11). The sparse data from Steamboat and Sutter Sloughs suggest that survival in these sloughs can be relatively high which could explain the relatively low mortalities we often see in Reach 1 (Table 7).

Environmental Influences in Reach 1

We examined relationships between the reconstructed estimates of mortality in Reach 1 and the factors shown in Table 7.

Water temperature at release site and at Freeport were the only significant environmental factors with a correlation coefficient of 0.69 and 0.63 (Table 8, Figure 5). The correlation coefficient for size of smolts was significant, but the sign indicated, again, that mortality increased as size increased which is contrary to population biology. Streamflows were not significantly correlated with mortality (Table 8).

We used multiple regression analysis to determine whether combinations of the environmental factors account for more variation than temperature, and to make sure that the temperature correlation was not masking the importance of streamflow. After the temperature factor was incorporated into the regression equation, streamflow did not account for any significant variation in the residual mortalities.

Water temperature at Freeport on release day accounted for 40% of the variation in mortality in Reach 1 (Table 9, Figure 5). The equation used to predict mortality through Reach 1 is :

$M_1 = -2.858 + (0.04851 * \text{ave water temperature °F at Freeport, CA})$.

Table 8. Correlation coefficients between estimated mortality using CWT chinook salmon smolts released at Sacramento and recovered at Chipps Island for Reach 1, Sacramento to Walnut Grove, (M_1), and selected environmental variables. Symbols: *, correlation significant at 0.05 level; **, correlation significant at the 0.01 level.

	Inst Water Temp °F @ Release Site (Sacramento)	Average Daily Water Temp °F @ Freeport on Release Date	Mean Daily Flow(CFS) at: Freeport on Release Date (QSAC)[1]	Freeport - (Sac to Court) (QSAC)[2]	No Smolts per Pound Smolts
Correlation Coefficients (r)	0.69**	0.63*	-0.49	-0.51	-0.66*

[1] - Mean of the mean daily Sacramento River flows at Sacramento on the day(s) smolts were released at Sacramento.
[2] - Mean of the mean daily Sacramento River flows at Freeport on the day(s) smolts passed from Sacramento to Courtland.

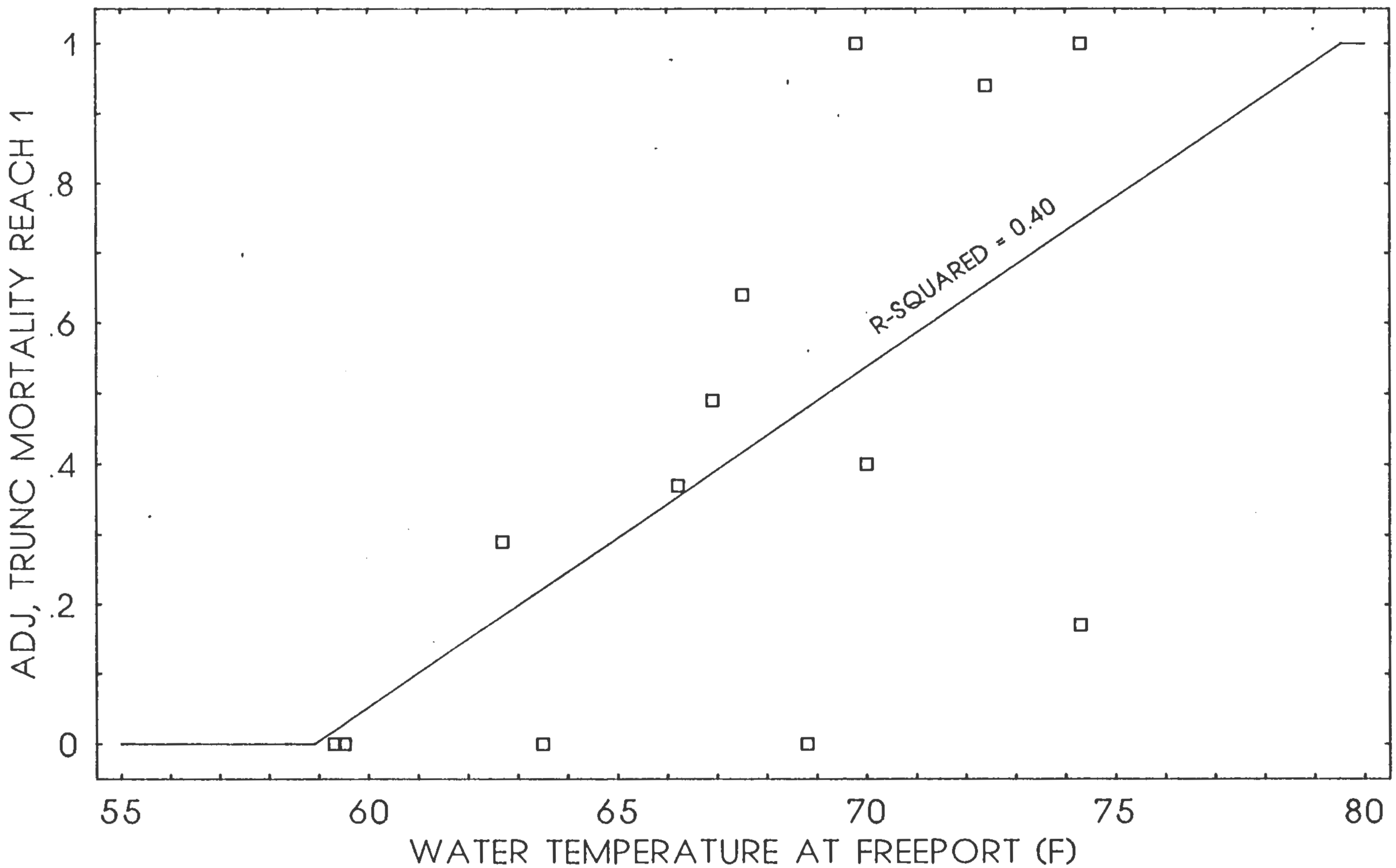


FIGURE 5. ESTIMATED CHINOOK SALMON SMOLT MORTALITY VERSUS AVERAGE DAILY WATER TEMPERATURE AT FREEPORT ON RELEASE DAY, REACH 1

Table 9. Linear regression between estimaetd mortality using CWT chinook salmon smolts released at Sacramento and recovered at Chipps Island for Reach 1, Sacramento To Walnut Grove, (M_1) and the average daily water temperature at the Freeport on release day.

Variable	Regression Coefficient	Standard Error	T-Statistic	Partial Correlation	Percent Variation Explained
Intercept	-2.858	1.211	-2.355	----	----
Average Daily Water Temp °F @ Freeport on Release Day	0.04851	0.01798	2.698	0.63	39.8

R-Squared = 0.3982
F-test: F ratio = 7.280
Standard error of regression = 0.3123

SIMULATIONS OF SURVIVAL BETWEEN SACRAMENTO AND CHIPPS ISLAND

Figures 6 and 7, and Table 10 illustrate simulations of overall predicted survival at varied water temperatures at Freeport, fractions diverted at Walnut Grove, and SWP plus SVP export pumping rates in the southern delta. Total mortality was calculated using Equations 1 and 3,

$$M_T = M_1 + M_{23} - (M_1*M_{23}) \text{ and} \qquad \text{Eq. 1}$$

$$M_{23} = M_2*P_2 + M_3*P_3. \qquad \text{Eq. 3}$$

Substituting Equation 3 into Equation 1 gives,

$$M_T = M_1 + (M_2*P_2 + M_3*P_3) - [M_1*(M_2*P_2 + M_3*P_3)]$$

$$M_T = M_1 + M_2*P_2 + M_3*P_3 - M_1*M_2*P_2 - M_1*M_3*P_3 \qquad \text{Eq. 6}$$

Total survival was calculated using the equation,

$$S_T = (1- M_T) \qquad \text{Eq. 7}$$

Survival values for environmental conditions not shown here can be calculated using Equations 6 and 7 and the three regression equations (Table 11).

The examples provided in the text below are meant to reflect some of the survival changes predicted by the model as the three parameters vary through conditions often seen in the delta.

The reader is cautioned in use of this model output. While specific values of survival are given, by necessity, for each environmental condition, it is wise to emphasize general trends and the relative magnitude of change in survival as conditions change. While changes in the absolute magnitude of survival often appear small with a given change in an environmental parameter, the relative magnitude of change is often great and will be reflected directly by increases in adult production. Since we used all available mortality indices in the regression analyses, we had no means to develop meaningful

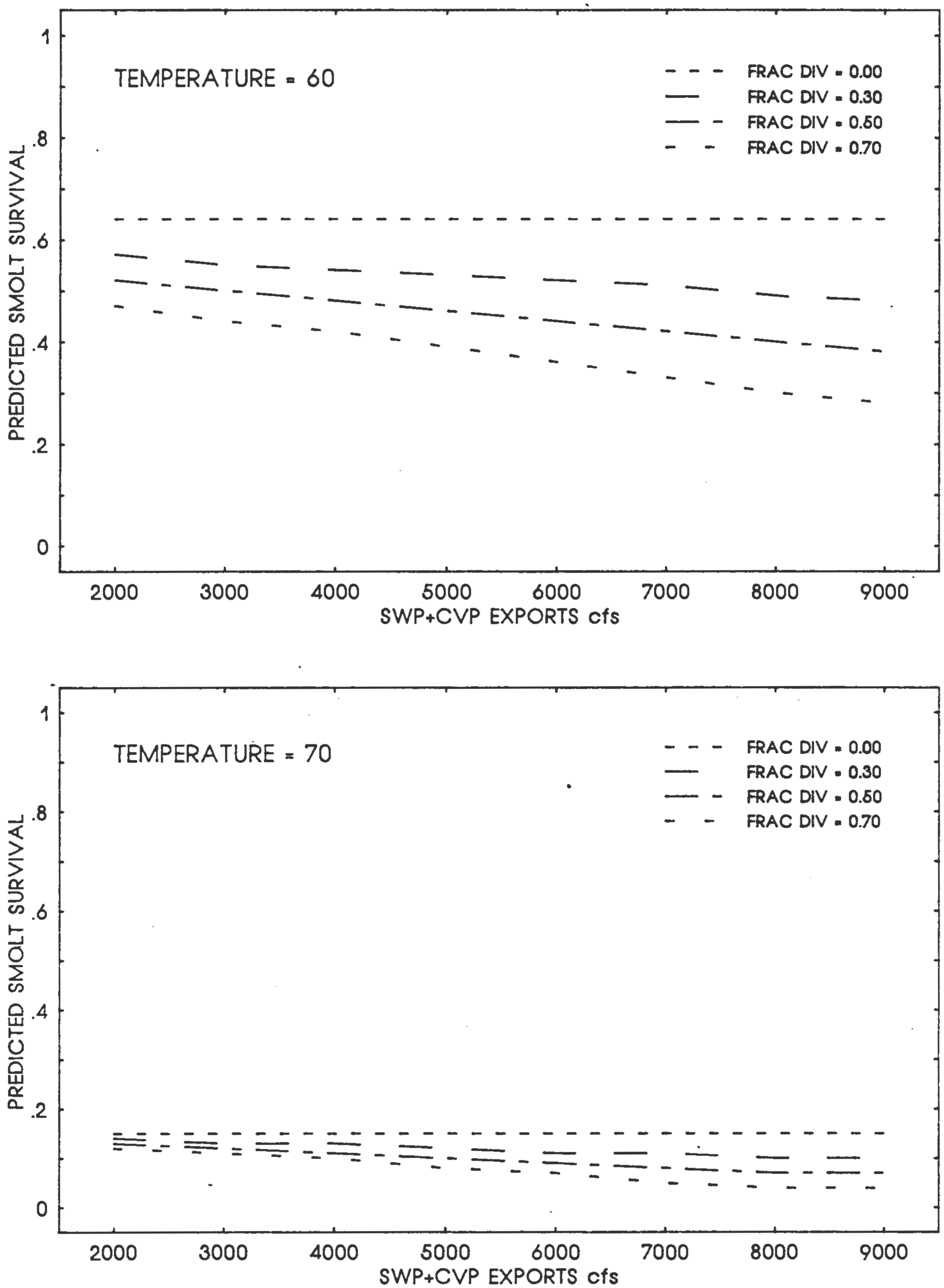
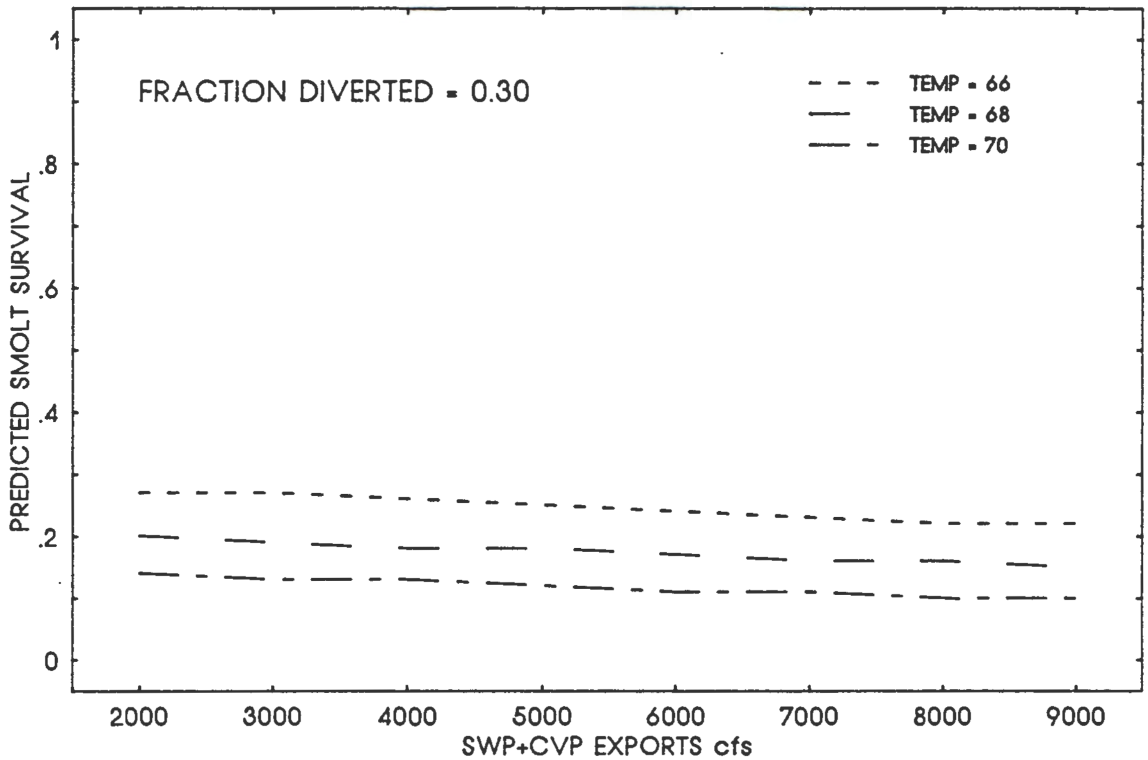


FIGURE 6. PREDICTED SMOLT SURVIVAL AT A SERIES OF WATER TEMPERATURES AND FRACTIONS DIVERTED AND SWP PLUS CVP EXPORT RATES



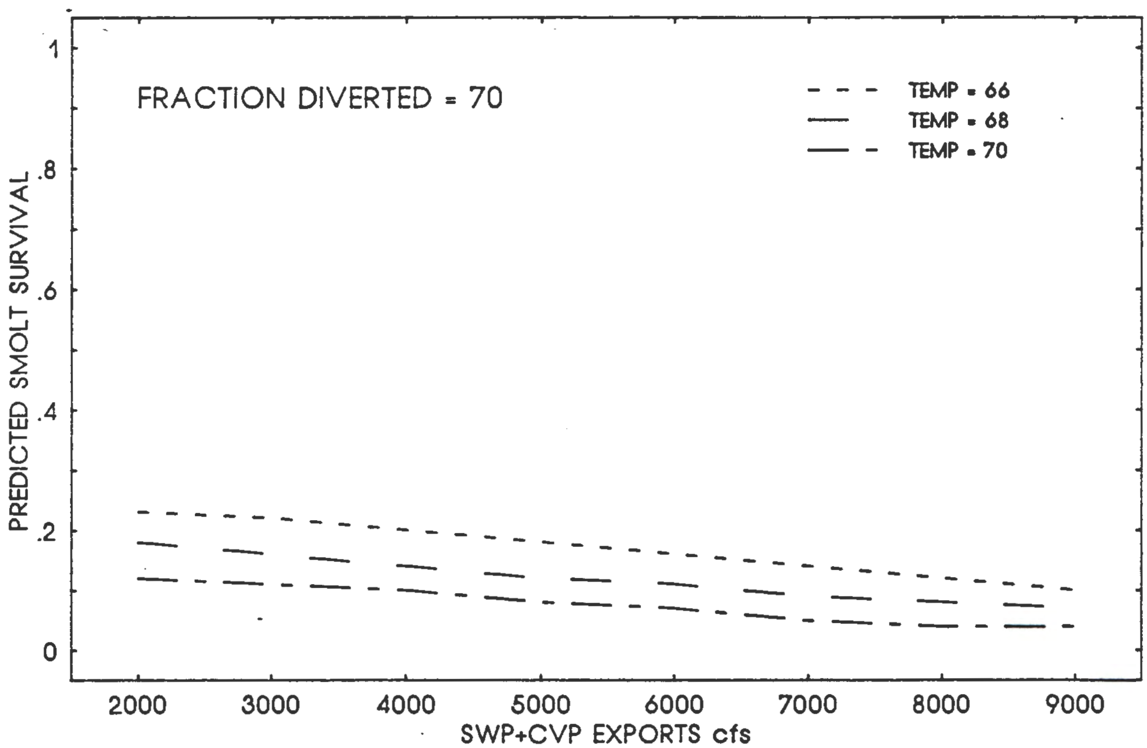


FIGURE 7. PREDICTED SMOLT SURVIVAL AT A SERIES OF WATER TEMPERATURES AND FRACTIONS DIVERTED AND SWP PLUS CVP EXPORT RATES

Table 10. Environmental parameters of the Sacramento River delta and corresponding total smolt survival through the three reaches, TFREE = water temperature at Freeport, °F; DIV = Fraction of water diverted at Walnut Grove; EXPORTS = total SWP and CVP exports from the southern delta; SURV123 = total survival of chimook salmon smolts between Sacramento and Chipps Island.

TFREE	DIV	EXPORTS	SURV123	TFREE	DIV	EXPORTS	SURV123
60.	0.	2000.	0.64	70.	0.	2000.	0.15
60.	0.	3000.	0.64	70.	0.	3000.	0.15
60.	0.	4000.	0.64	70.	0.	4000.	0.15
60.	0.	5000.	0.64	70.	0.	5000.	0.15
60.	0.	6000.	0.64	70.	0.	6000.	0.15
60.	0.	7000.	0.64	70.	0.	7000.	0.15
60.	0.	8000.	0.64	70.	0.	8000.	0.15
60.	0.	9000.	0.64	70.	0.	9000.	0.15
60.	0.3	2000.	0.57	70.	0.3	2000.	0.14
60.	0.3	3000.	0.55	70.	0.3	3000.	0.13
60.	0.3	4000.	0.54	70.	0.3	4000.	0.13
60.	0.3	5000.	0.53	70.	0.3	5000.	0.12
60.	0.3	6000.	0.52	70.	0.3	6000.	0.11
60.	0.3	7000.	0.51	70.	0.3	7000.	0.11
60.	0.3	8000.	0.49	70.	0.3	8000.	0.1
60.	0.3	9000.	0.48	70.	0.3	9000.	0.1
60.	0.5	2000.	0.52	70.	0.5	2000.	0.13
60.	0.5	3000.	0.5	70.	0.5	3000.	0.12
60.	0.5	4000.	0.48	70.	0.5	4000.	0.11
60.	0.5	5000.	0.46	70.	0.5	5000.	0.1
60.	0.5	6000.	0.44	70.	0.5	6000.	0.09
60.	0.5	7000.	0.42	70.	0.5	7000.	0.08
60.	0.5	8000.	0.4	70.	0.5	8000.	0.07
60.	0.5	9000.	0.38	70.	0.5	9000.	0.07
60.	0.7	2000.	0.47	70.	0.7	2000.	0.12
60.	0.7	3000.	0.44	70.	0.7	3000.	0.11
60.	0.7	4000.	0.42	70.	0.7	4000.	0.1
60.	0.7	5000.	0.39	70.	0.7	5000.	0.08
60.	0.7	6000.	0.36	70.	0.7	6000.	0.07
60.	0.7	7000.	0.33	70.	0.7	7000.	0.05
60.	0.7	8000.	0.3	70.	0.7	8000.	0.04
60.	0.7	9000.	0.28	70.	0.7	9000.	0.04

(Table 10 cont)

DIV	TFREE	EXPORTS	SURV123
0.	66.	2000.	0.3
0.	66.	3000.	0.3
0.	66.	4000.	0.3
0.	66.	5000.	0.3
0.	66.	6000.	0.3
0.	66.	7000.	0.3
0.	66.	8000.	0.3
0.	66.	9000.	0.3
0.	68.	2000.	0.22
0.	68.	3000.	0.22
0.	68.	4000.	0.22
0.	68.	5000.	0.22
0.	68.	6000.	0.22
0.	68.	7000.	0.22
0.	68.	8000.	0.22
0.	68.	9000.	0.22
0.	70.	2000.	0.15
0.	70.	3000.	0.15
0.	70.	4000.	0.15
0.	70.	5000.	0.15
0.	70.	6000.	0.15
0.	70.	7000.	0.15
0.	70.	8000.	0.15
0.	70.	9000.	0.15
.3	66.	2000.	0.27
.3	66.	3000.	0.27
.3	66.	4000.	0.26
.3	66.	5000.	0.25
.3	66.	6000.	0.24
.3	66.	7000.	0.23
.3	66.	8000.	0.22
.3	66.	9000.	0.22
.3	68.	2000.	0.2
.3	68.	3000.	0.19
.3	68.	4000.	0.18
.3	68.	5000.	0.18
0.3	68.	6000.	0.17
0.3	68.	7000.	0.16
0.3	68.	8000.	0.16
0.3	68.	9000.	0.15
0.3	70.	2000.	0.14
0.3	70.	3000.	0.13
0.3	70.	4000.	0.13
0.3	70.	5000.	0.12
0.3	70.	6000.	0.11
0.3	70.	7000.	0.11
0.3	70.	8000.	0.1
0.3	70.	9000.	0.1
0.7	66.	2000.	0.23
0.7	66.	3000.	0.22
0.7	66.	4000.	0.2
0.7	66.	5000.	0.18
0.7	66.	6000.	0.16
0.7	66.	7000.	0.14
0.7	66.	8000.	0.12
0.7	66.	9000.	0.1
0.7	68.	2000.	0.18
0.7	68.	3000.	0.16
0.7	68.	4000.	0.14
0.7	68.	5000.	0.12
0.7	68.	6000.	0.11
0.7	68.	7000.	0.09
0.7	68.	8000.	0.08
0.7	68.	9000.	0.07
0.7	70.	2000.	0.12
0.7	70.	3000.	0.11
0.7	70.	4000.	0.1
0.7	70.	5000.	0.08
0.7	70.	6000.	0.07
0.7	70.	7000.	0.05
0.7	70.	8000.	0.04
0.7	70.	9000.	0.04

Table 11. Summary of equations and factors used to construct the models for simulating the survival of chinook salmon smolts between Sacramento and Chipps Island.

Reach	Factors Used To Estimate Mortality	Equation Used To Estimate Mortality For Reach
Sacramento to Walnut Grove	Average Daily Water Temp °F at Freeport on Release Day	$M_1 = \{(-2.858) + (0.04851 * \text{Ave Water Temp, °F, at Freeport, CA})\}$
Walnut Grove to Chipps Is via Mokelumne River System	Average Daily Water Temp °F at Freeport on Release Day	$M_2 = \{(-0.5809) + (0.01793 * \text{Ave Water Temp, °F, at Freeport, CA}) + (0.0000418 * \text{SWP+CVP Exports})\}$
Walnut Grove to Chipps Is via Sacramento River System	Average Daily Water Temp °F at Freeport on Release Day	$M_3 = \{(-1.766) + (0.03489 * \text{Ave Water Temp, °F, at Freeport, CA})\}$

error estimates beyond considering the standard error of the regressions (Tables 3, 6 and 9).

Effects of Fraction Diverted

We chose a range of diversion fractions that closely represented conditions with the Delta Cross Channel gates open (0.70) versus closed (0.30).

Survivals increased as the fraction of water diverted at Walnut Grove decreased (Figure 7). The greatest survival benefit from a decrease in fraction diverted into the central delta (from about 0.3 to 0.5 survival) is at low water temperatures (60°F). At water temperatures of about 70°F, however, even a major reduction in the fraction diverted, from 0.70 to 0.30, results in a rather minor effect on survival.

Although there is no present means to eliminate diversions into the central delta, we also estimated the survival when the fraction diverted was zero. This eliminated any mortality in Reach 2 and the model predicted total survival between Sacramento and Chipps Island to be 0.64 at a temperature of 60°F. This can be compared to a model prediction of survival of 0.47 at 60°F when the fraction diverted was 0.70 and exports were low at 2000 cfs. When no water is diverted at Walnut Grove and the temperature is 70°F, the model predicted a survival of 0.15. This, in turn, could be compared to a model survival of 0.12 at 70°F, again, with exports at 2000 cfs and fraction diverted at 0.70. The above example infers that a relatively large increase in survival can be gained at lower water temperatures by eliminating high levels of diversion at Walnut Grove, but relatively very little can be gained at higher water temperatures.

Effect of Water Temperature

Survival increases as water temperature decreases and model results indicate rather large increases in survival over a 10°F decrease in temperature when the other two factors are held constant (Figure 7). Managing for such a large drop in temperature, however, is not practical. A lowering of temperature of from two to four degrees at 66°F to 70°F provides a measurable increase in survival (from about 0.05 to 0.10 survival units) (Figure 8). The survival benefits of a temperature decrease appear slightly better when the fraction diverted at Walnut Grove is less.

Effect of Exports

Survival increases as total SWP and CVP export pumping rate decreases. The greatest relative survival benefits of reduced exports are seen at lower temperatures of 60°F and at high fraction diverted (0.70) (Figure 5). A decrease in exports from 9000 down to 2000 cfs yielded an improvement in survival from about 0.3 to 0.5.

A major question remains relative to the survival benefit of eliminating exports. We have not measured survival with a total pump curtailment and the model can not be expected to predict it under those conditions.

CONCLUSIONS

We have developed a smolt survival model based on multiple regression analyes using three environmental parameters. These factors were justified for inclusion by their statistically significant relationships with survival, and appear biologically sound. As is true with all modeling of complex systems, other factors that also influence smolt survival could have been omitted due to data limitations or the fact that we restricted our choice to environmental parameters that had a potential to be changed through management actions.

Our modeling has been successful in helping us to gain a better understanding of the potential factors influencing survival and to identify critical assumptions and data gaps in need of further research. There is a need :

1) to test further the assumption that smolts are diverted in proportion to the amount of flow diverted at selected sites,
2) to gain further estimates of smolt survival in Steamboat and Sutter Sloughs, and then add these sloughs to the model,
3) to estimate survival from CWT smolt releases in the central delta (Reach 2) under low export rates and with positive flow in the western San Joaquin River, and
4) to evaluate further the reasons for the high unexplained mortality in the central delta.

We believe the model is a reasonable representation of several key factors influencing smolt survival in the Sacramento River portion of the delta, and while uncertainties remain in our understanding, it is a useful tool to assess the benefits of decreasing the fraction of Sacramento River that is diverted at Walnut Grove, the water temperature in the Sacramento River at Freeport, and the total exports of the SWP and CVP during the fall-run smolt downstream emigration period. The lessening of these three factors and their impacts on smolt surival can be achieved through a variety of potential structural and operational measures such as fish screens, Delta Cross Channel closures, fish guidance facilities and traps, tidal gates, increased flows, increased riparian vegetation, and decreased spring exports.

While survival benefits can potentially be achieved by each of the above measures, we believe that the most effective ones are those that keep smolts out of the central and southern portions of the delta where mortality is highest.

We expect that the model will be used for a diversity of activities in addition to our own Delta Salmon Team evaluations and subsequent testimony in the CSWRCB Bay/Delta Proceedings. Some of these other activities include environemental impact analyses of proposed projects in the delta; evaluations relative to the Article Seven Negotiations between CDWR, USBR and CDFG; and the CDWR and CDFG Four Pumps Agreement. We caution that the model represents survival under existing delta conditions and suggest that when the model is used to predict smolt survival under an altered delta environment that this concern be addressed.

The model is a definite improvement over the earlier, more general, smolt survival model which used the magnitude of flow as an index parameter to reflect the influence of flow, temperature and fraction diverted at Walnut Grove on survival. The flow-only model under-estimated survival under low temperature and low flow conditions which can occur in April and early May in low runoff years. As noted earlier, this was because we had not measured survival at low flows and low temperatures.

We have not been able to measure suvival when flows were increased and temperatures remained constant. This has prevented us from thoroughly evaluating the independent effects of flow. While we desire to define these effects, in practice this appears infeasible. We believe that as flows increase, smolt survival is greater due to both lessening water temperatures and fraction diverted and possibly flow itself.

It is important to remember, that of the simulations of survival we provided, the largest benefits in survival are seen for a 10°F decrease in temperature, in practice temperature decreases of several degrees are difficult to achieve through management changes. This limitation is due to the large influence of air temperature on water temperature. Further evaluation by the Delta Salmon Team will quantify the cost of lowering temperatures by various means.

We encourage suggestions for improvement of the smolt survival model and plan to refine it as additional data becomes available.

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APPENDIX 1. Data set including survival/mortality indices and environmental parameters from which regresison analyses were performed. Expanded description of column heading abbreviations follow data set.

REACH 1

CWT	RELDATEB	SURV_T	SURVADJ	MORT123A	MORT3RCS	MORT2RCS	MORT23RC	MORT1RCS	SIZEno#	LENGTHmm	T@REL	TFREEMAX	TFREEAVE	QSAC_R	QSAC_S_C
66202	06/05/78	0.	0.	1.	0.67	0.97	0.86	1.	56.	91.	73.	71.1	69.8	13200.	13400.
66205	06/04/79	0.42	0.23	0.77	0.63	0.91	0.82	0.	98.	75.	68.	69.7	68.8	11980.	12650.
66208	06/02/80	0.32	0.18	0.82	0.57	0.85	0.65	0.49	61.	96.	62.	67.3	66.9	13400.	13367.
66211	06/04/80	0.35	0.19	0.81	0.54	0.84	0.7	0.37	57.	98.	62.	66.6	66.2	13350.	13600.
66214	06/02/81	0.02	0.01	0.99	0.78	0.86	0.83	0.94	52.	90.	76.	72.9	72.4	10650.	10170.
66217	06/04/81	0.	0.	1.	0.83	0.9	0.88	1.	55.	90.	76.	75.2	74.3	9690.	9485.
66220	05/11/82	1.48	0.82	0.18	0.31	0.73	0.41	0.	95.	76.	59.5	59.7	59.5	45200.	44500.
66218	05/12/82	1.54	0.86	0.14	0.3	0.7	0.39	0.	71.	78.	59.4	59.5	59.3	43800.	42650.
66221	06/04/82	0.84	0.36	0.64	0.42	0.72	0.49	0.29	93.	76.	68.	62.8	62.7	32400.	31600.
B61408/7	05/05/88	0.65	0.38	0.64	0.45	0.89	0.74	0.	68.	77.5	62.	63.5	63.5	9670.	11123.
66261/2	06/23/88	0.09	0.05	0.95	0.83	1.	0.94	0.17	55.	88.6	74.	75.2	74.3	12000.	12800.
63110	06/01/89	0.18	0.09	0.91	0.59	0.83	0.75	0.64	54.	*	67.	68.7	67.5	13604.	13319.
63115/7	06/14/89	0.21	0.12	0.88	0.68	0.86	0.8	0.4	61.9	*	69.5	71.2	70.	12748.	12748.

REACH 2

CWT	RELDATEB	SURV_T	SURVADJ	MORT23AJ	MORT3ADJ	MORT2ADJ	SIZEno#	LENGTHmm	T@REL	TFREEMAX	TFREEAVE	QSAC_R	DIV_WG	QWEST_CI	QOUT_CI	EXPORTS	TIDE	CCG
66224	05/16/83	1.06	0.59	0.41	0.34	0.65	87.	79.	60.	60.3	60.1	69400.	0.227	35241.	77531.	3730.	1	close
66227	06/11/84	0.61	0.34	0.66	0.42	0.81	74.	82.	66.	66.2	65.5	16200.	0.616	1085.	8051.	5596.	8	open
66238/41	05/10/85	0.34	0.19	0.81	0.57	0.94	78.	78.	64.	61.7	61.3	13500.	0.643	-60.	6727.	6517.	1	open
66243	05/28/86	0.35	0.19	0.81	0.62	0.92	80.	81.	73.	72.5	71.6	14000.	0.637	6923.	13401.	5281.	1	open
66253/4	04/28/87	0.67	0.37	0.63	0.53	0.77	74.	81.	66.5	68.	67.3	11800.	0.412	889.	5698.	5616.	3	close
66256/7	05/01/87	0.4	0.22	0.78	0.51	1.	71.	79.	66.5	68.2	67.5	11200.	0.548	558.	4816.	5436.	1	open
B61402/3	05/03/88	0.7	0.39	0.61	0.48	0.81	61.	76.	62.	64.4	63.5	7870.	0.387	-2361.	6364.	7497.	3	close
B61404/5	05/06/88	0.76	0.42	0.58	0.29	0.82	64.5	78.	61.	63.5	62.1	11600.	0.547	-2957.	5854.	8020.	1	open
66259/60	06/21/88	0.17	0.09	0.91	0.78	1.	57.	90.	73.	72.5	72.	11400.	0.412	-2569.	3117.	6454.	5	close
66250	06/24/88	0.02	0.01	0.99	0.81	1.	59.	89.	76.	75.2	74.3	13000.	0.535	-1477.	2423.	6094.	8	open
63111	05/02/89	0.84	0.47	0.53	0.34	0.63	60.7	*	60.5	61.5	60.8	12578.	0.654	-299.	7578.	4224.	8	open
63108	06/02/89	0.35	0.2	0.8	0.73	0.84	44.	*	69.	69.8	68.7	13151.	0.647	-2581.	8140.	4919.	3	open
65805/3	06/15/89	0.21	0.12	0.88	0.91	0.87	54.1	*	71.	71.8	70.9	11461.	0.671	-1262.	6698.	4568.	8	open

REACH 3

CWT	RELDATEB	SURV_T	SURVADJ	MORT3ADJ	SIZEno#	LENGTHmm	T@REL	TFREEMAX	TFREEAVE	QSAC_R	QRIO_RV	QWEST_CI	QOUT_CI	EXPORTS	TIDE	CCG
66223	05/20/83	1.18	0.68	0.34	77.	81.	61.	63.	62.5	52400.	42989.	35028.	77042.	4150.	5	close
66229	06/13/84	1.05	0.58	0.42	88.	77.	66.	67.3	66.8	13900.	6395.	1108.	8083.	5497.	3	open
66235	05/11/85	0.77	0.43	0.57	78.	78.	66.	61.7	61.3	14000.	7051.	-147.	6898.	6690.	5	open
66248	05/30/86	0.68	0.38	0.62	85.	81.	74.	72.5	72.	13700.	6870.	6964.	13439.	5612.	5	open
66255	04/29/87	0.85	0.47	0.53	76.	79.	67.	68.2	67.4	11600.	6451.	1046.	5619.	5524.	3	close
66258	05/02/87	0.88	0.49	0.51	73.	80.3	64.	64.4	67.5	10900.	5046.	511.	4367.	5147.	1	open
63101	05/04/88	0.94	0.52	0.48	54.	88.	63.	64.4	63.9	7970.	6029.	285.	8032.	7025.	3	close
63102	05/07/88	1.28	0.71	0.29	53.	67.	61.	60.8	59.9	12100.	7322.	-271.	8146.	7959.	1	open
66263	06/22/88	0.4	0.22	0.78	55.	90.	75.	74.3	73.4	11100.	7357.	-2569.	3117.	6500.	6	close
63103	06/25/88	0.34	0.19	0.81	52.	94.	74.	73.4	72.9	13400.	5586.	-1736.	2491.	6253.	8	open
63112	05/03/89	1.19	0.66	0.34	64.8	*	62.	63.1	62.1	11178.	4280.	-247.	7594.	3942.	3	open
63107	06/02/89	0.48	0.27	0.73	48.	*	67.	69.8	68.7	13151.	7647.	-1563.	7673.	5373.	3	open
H6114102	06/16/89	0.16	0.09	0.91	57.9	*	73.	70.5	70.	14036.	7709.	-1243.	5702.	4709.	8	open

(Appendix 2 continued)

Column Heading Descriptions

Abbreviations	Expanded descriptions
CWT	Coded Wire Tag Identification
RELDATEB	Beginning date of CWT smolt release
SURV_T	Survival index based on trawl recovery
SURVADJ	Adjusted suvival index based on trawl recovery
MORT123A	Adjusted mortality index of smolts released at Sacramento and recovered at Chipps Island
MORT23AJ	Adjusted mortality index of smolts released at "Courtland" and recovered at Chipps Island
MORT3ADJ	Adjusted mortality index of smolts released at Ryde and recovered at Chipps Island
MORT2ADJ	Adjusted mortality index of smolts traveling through Reach 2
MORT3RCS	Reconstructed mortality of smolts traveling through Reach 3
MORT2RCS	Reconstructed mortality of smolts traveling through Reach 2
MORT23RC	Reconstructed mortality of smolts traveling through Reaches 2 and 3
MORT1RCS	Reconstructed mortality of smolts traveling through Reach 1
SIZEno#	Mean size of CWT smolts in units of number of smolts per pound of smolts
LENGTHmm	Mean length of CWT smolts in millimeters
T@REL	Instantaneous water temperature at release site, °F
TFREEMAX	Maximum daily water temperature at Freeport, CA on release day, °F
TFREEAVE	Average daily water temperature at Freeport, CA on release day, °F
QSAC_R	Mean of the mean daily Sacramento River flow on release day(s), cfs
QSAC_S_C	Mean of the mean daily Sacramento River flow on the day(s) smolts emigrated from Sacramento to "Courtland", mm
DIV_WG	Mean daily fraction diverted at Walnut Grove on the day(s) smolts were at Walnut Grove
QRIO_RV	Mean daily Rio Vista flow on the day(s) smolts were emigrating past Rio Vista, cfs
QWEST_CI	Mean daily flow past Jersey Point on the day(s) smolts were emigrating past Chipps Island, cfs
QOUT_CI	Mean daily net delta outflow on the day(s) smolts emigrated past Chipps Island, cfs
EXPORTS	Mean of the mean daily CVP plus SWP export pumping rate on the day(s) smolts emigrated from Walnut Grove to Chipps Island via the central delta, cfs
TIDE	Tide phase index at release site
CCG	Status of the Delta Cross Channel Gates on the day(s) smolts emigrated past Walnut Grove

Exhibit 31, entered by the U.S. Fish and Wildlife Service for the State Water Resources Control Board 1987 Water Quality/Water Rights Proceeding on the San Francico Bay/Sacramento-San Joaquin Delta.

The Needs of Chinook Salmon, *Oncorhynchus tshawytscha*,
in the Sacramento-San Joaquin Estuary

Section 1

SYNOPSIS OF SALMON MANAGEMENT NEEDS IN THE ESTUARY

Introduction

The main objective of this report is to describe the conditions that provide for the protection of chinook salmon in the Sacramento-San Joaquin Estuary. This information should help the Board in setting standards that will provide reasonable protection of beneficial uses in the Estuary. Chinook salmon are a beneficial use that support an intense commercial and recreational fishery whose annual catch averages about 400,000 fish. This represents a significant economic and recreational resource for California.

Chinook use the Bay and Delta habitat as a salmon nursery and for juvenile and adult migrations to and from the ocean and their freshwater habitat. Available evidence indicates that existing water quality standards in the 1978 Delta Plan are inadequate for salmon protection and will result in the survival of juvenile chinook migrating through either the Sacramento or San Joaquin Delta being substantially less than historical survival rates.

Stock Status and the Delta Problem for Salmon

Four runs of chinook salmon (fall, late-fall, winter and spring) are produced in the Central Valley. Fall-run are the focus of this report and comprise over 90% of all spawners. The Sacramento Basin accounts for over 80% of the production. Naturally produced chinook stock in Valley streams have declined by over 50% since the early 1950's. These losses are attributable to habitat reduction in both upstream and estuarine areas.

The evidence presented in this report will demonstrate that habitat alterations in the Delta limit salmon production primarily through reduced survival during the outmigrant (smolt) stage. These lower survivals are associated with decreases in the magnitude of flow through the estuary, increases in water temperatures and water project diversions in the Delta.

Smolt mortality in the Estuary will impact resulting adult salmon population levels. However, other factors that influence stocks and their measurement in upstream and oceanic waters make that impact difficult to quantify. Nevertheless, increasing smolt survival rates through the Delta is a critical step toward restoring natural salmon production in the Central Valley.

Since the early 1970's, juvenile chinook salmon produced at the Feather River, Nimbus and Mokelumne River hatcheries have been trucked downstream and released in the Sacramento River at Rio Vista or adjacent to Carquinez Strait. Since these fish are not exposed to Delta hazards their contribution to the ocean fishery and to subsequent spawning runs is often high. Chinook salmon from Coleman and Merced River hatcheries are released in upriver areas near the hatcheries to prevent the straying of returning spawners which occurs when juvenile salmon from upriver are released in the Estuary. The release of hatchery fish in the lower estuary has enabled a relatively intense ocean fishery to remain stable concurrent with reduced natural salmon populations. The success of the hatchery program, however, increases the risk of overharvesting natural stocks or of hatchery fish that must pass through the Delta.

Estuarine Salmon Ecology and Conditions for Improved Salmon Protection

Juvenile Salmon Migration and Abundance

Fall-run salmon migrate through the Estuary to the ocean from April through June with peak abundances seen in May. Salmon of the other three runs migrate between fall and early spring.

The abundance of smolts at Chipps Island is positively correlated to Sacramento River flow at Rio Vista.

Smolt migration through the Bay/Delta system takes about 10 to 15 days. Rough estimates of the annual number of fall-run smolts leaving the Delta from 1978 to 1986 ranged from about 10 to 50 million fish. These represent about 200,000 to one million adults respectively to the ocean fishery.

Smolt Survival

Sacramento River Delta

The survival of marked hatchery smolts through the Sacramento Delta between Sacramento and Suisun Bay is positively correlated to flow and negatively correlated to both temperature and the percent of the flow diverted off the Sacramento River through the Delta cross channel and Georgiana Slough at Walnut Grove.

Smolt survival increased with increasing Sacramento River flow at Rio Vista, with maximum survival observed at or above

20,000 to 30,000 cfs. This relation was based on two independent measures of survival.

Smolt survival is highest when water temperatures are below 66°F. Temperatures of 76°F or higher are lethal to salmon and stress would occur as temperatures approach that level.

Diverting smolts off the Sacramento River into the Central Delta lessens their survival. Evidence of this is 1) when about 65% of the Sacramento River was diverted to the Central Delta, tagged smolts released immediately above the Walnut Grove diversion point survived at only 50% of the rate of those released immediately below Walnut Grove, 2) when the cross channel was closed, the difference in survival for the two groups was zero at high flows, and about 25% at low flows, and 3) survival of tagged smolts released in the Central Delta was about 50% less than those released in the Sacramento River below Walnut Grove during years of low flow and similar temperatures. Hence, closing the Cross channel is of considerable benefit to salmon survival at low flows when temperatures are acceptable.

Since both temperature and diversions increase as flows decrease, it is difficult to detemine the relative contributions of these factors to changes in survival observed in the Estuary. We believe, however, that both temperature and diversions cause survival to decrease as flows decrease.

Existing flow and operational standards in the 1978 Delta plan are inadequate. Salmon flow standards at Rio Vista range from 1,000 to 5,000 cfs which would yield from zero to 2% survival based on the relationship between smolt survival and flow. Striped bass Delta outflow standards in May and June afford higher protection and would improve survival to an estimated 5% in dry years to 35% in wet years.

Water development in the Sacramento Valley has reduced inflow to the Delta during the April-June smolt migration period. These reductions combined with the present Delta diversions off the Sacramento River have been enough to reduce average smolt survival in the Sacramento Delta by at least 30% since 1940.

Potential measures to improve smolt survival through the Sacramento Delta include: increasing flows, closure or screening of the Delta cross channel, elimination of reverse flows in the lower San Joaquin and reducing Project export levels in the southern Delta.

San Joaquin Delta

Typical conditions in the San Joaquin Delta are detrimental for smolt survival. This is attributed largely to low Delta inflow from the San Joaquin River, the effect of which is accentuated by diversions typically exceeding inflow during smolt migration periods. High water temperatures (typically 70°F in May) associated with low flows also stress juvenile salmon.

Survival of tagged smolts migrating from the San Joaquin drainage through the Delta increased with increased Delta inflows. Smolt survival and resulting adult production was most favorable in wet years when flows at Vernalis during smolt migration was greater than total CVP-SWP exports. The benefit of increased river flows to returning spawner numbers reflects benefits to juvenile survival both upstream and in the Delta.

Survival of tagged smolts released in the southern Delta was higher for smolts migrating down the San Joaquin River than for those diverted to the west toward the CVP-SWP pumps via upper Old River indicating that diversion is a key factor affecting smolt survival. In two of the three years studied, survival of fish released in upper Old River, and thus exposed to the Projects' diversions, was 40% to 80% lower than those released in the San Joaquin below the upper Old River Junction. In the third year there was no difference observed.

The rate at which smolts migrated through the San Joaquin Delta about doubled as inflow at Vernalis increased from 2,000 to 7,000 cfs.

There are no existing San Joaquin River flow standards in the 1978 Delta Plan for smolt survival. Project export limits in May and June provide some protection. Fish screen operational criteria also provide some protection after the fish are diverted from the river.

Potential measures to improve smolt survival in the San Joaquin Delta include: reductions in CVP-SWP export levels, a barrier or a screen at the head of upper Old River, increased flows, and elimination of reverse flows in the lower San Joaquin River. Continued juvenile survival studies are needed in the San

Joaquin system to better enable us to evalute varied salmon protective measures.

San Francisco Bay

Available data is too sparse to draw any conclusions on the influence of Delta outflow on smolt survival in the Bay. Data from 1984 indicates survival through the Bay for large juvenile salmon was relatively high (81%) for a rather low Delta outflow index of 10,000 cfs. Ocean tag recoveries available in 1988 and 1989 reflecting smolt tag releases in the Bay in 1985 and 1986 will provide two more estimates of survival through the Bay at outflows of 10,000 cfs.

Salmon Rearing

Fall run chinook fry rear both upstream and in the Estuary with peak abundances seen in the Delta in February and March. As Delta inflow increases, fry become both more numerous and more widely distributed in the estuary.

The survival of tagged fry was greater in the upper Sacramento River than in the Delta, while that in San Francisco Bay was the lowest.

Fry released in the northern Delta appeared to survive better than those released in the Central Delta except in years of very high Delta inflow.

Chinook fry that rear in the Delta contribute some portion of Central Valley salmon production with that proportion increasing as runoff increases. That contribution is probably small relative to that upriver rearing but still significant.

Adult Migration

Chinook spawners of the four runs migrate through the Estuary at different times throughout the year. Adult migration data was gained with CDFG sonic tag studies in the mid 1960's. Findings from that work indicated that: migrations through the Estuary are aided by positive downstream flows of "homestream water" and temperatures less than 66^{o}F.

Dissolved oxygen concentrations below 5 mg/l block upstream migration.

State of California
The Resources Agency
Department of Water Resources

ESTIMATING THE EFFECT OF CHANGING DELTA ENVIRONMENTAL CONDITIONS ON SACRAMENTO BASIN FALL RUN CHINOOK SALMON STOCK

Analysis Made Under the Direction of the Delta Salmon
Team of the Five Agency Salmon Management Group

By

D.W. Kelley, Sheila Greene, W.T. Mitchell

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CHAPTER 1. INTRODUCTION

In late 1987, the state and federal agencies responsible for water development and fisheries submitted to the California State Water Resources Control Board (CSWRCB), a "Plan to Assess Central Valley Salmon Problems and Solutions In Connection with the SWRCB Delta Hearings". It was submitted as California Department of Fish and Game (CDFG) Exhibit 65. Assessment is to be done by three teams from the United States Fish and Wildife Service (USFWS), National Marine Fisheries Service (NMFS), United States Bureau of Reclamation (USBR) and from the California Department of Water Resources (CDWR) and CDFG. The goal is to analyze actions which will improve survival rates of juvenile salmon emigrating downstream through the Sacramento or San Joaquin rivers and the Delta. The plan outlines four major tasks.

1. Develop a description of actions that have a good chance of increasing juvenile survival rates in a major way.
2. Estimate how those actions would increase survival rates.
3. Predict how those actions would increase salmon catch and spawning escapements.
4. Estimate how much these actions would cost.

Our concept of how to help accomplish these tasks was to use existing knowledge to identify problems facing salmon smolts as they emigrated through the Delta, to help CDWR and USBR engineers modify their baseline operation study of how the State Water Project (SWP)/Central Valley Project (CVP) was now working in ways that would mitigate those problems, to assess the benefits to salmon in terms of long term ocean catch and spawning escapement, and the costs to the water projects in terms of water deliveries that could not be made to customers because of the operating changes made to benefit salmon.

The entire process was to use four models in sequence. These four models are:

1. The DWRSIM model which simulates reservoir storage, river flow and water deliveries for the SWP/CVP (CDWR, 1985).
2. The USBR water temperature model developed by Jack Rowell to simulate reservoir and river temperatures in the Sacramento River (Rowell, 1990).
3. The USFWS Delta Smolt Survival model developed by Kjelson, Greene and Brandes to calculate mortality rate of salmon smolts as they emigrate through the Delta on the basis of water temperatures, diversion rates and exports from the Delta as they are calculated by the first two models (Kjelson, Greene and Brandes, 1989).
4. The Mitchell Model which calculates long term ocean catch and spawning escapement in the upper Sacramento River and its major tributaries from the annual estimates of Delta mortality rates that result from sequential use of the previously named models.

All four of these models include many assumptions that are based on less than desirable data. All should be used with the understanding that they are expressions of our current understanding of how things work and that as research continues, this understanding will change and the models should be revised or abandoned for better ones.

We originally thought that the key question was whether linking these four models, with all their uncertainty, provides new understanding to aid the discussions of how the CDWR and USBR might modify their operations of the SWP and CVP to assist salmon. The response of collegues who reviewed our draft, suggests that the approach is good but that the models, especially the Mitchell Model that converts smolt survival rates to ocean catch and spawning escapement, are not well enough tested to produce believable results. They recommend various approaches to testing and modification which we will discuss in the last chapter of this report. At their suggestion, we offer this report to illustrate our approach and encourage testing and further development.

Descriptions of the first three of these models have been published and we will not describe them further here. The Mitchell Model was developed specifically for this task and is therefore described in detail in Chapter 2.

Chapter 3 begins to illustrate the approach with a simulation from DWRSIM designated Study 75D. This is one of several baseline studies produced to illustrate reservoir storage, river flows and exports from the Delta with 1990 levels of export demand and existing facilities (except for a water temperature control device in Shasta Reservoir) and operating policies and rules. Linking the four models results in a long term estimation and trends over a 57 year period of ocean salmon catch and spawning escapement in the various rivers of the Sacramento Riversystem if the projects were operated in this fashion.

The illustration is continued in Chapter 4 by applying the process to Operation 144C. Study 144C is aimed at increasing fall run chinook as much as possible with existing reservoirs and other facilities and without harming salmon stocks in their river habitat above the Delta. Like Study 75D, it does assume that a water temperature control device has been installed in Shasta Reservoir.

Chapter 5 is our summary and discussion of results and our experience in attempting this approach. We also include some recommendations about how further progress can be made.

ACKNOWLEDGEMENTS

The authors have tried to make the assumptions of these models and their linkage reasonable and to base them on the current biological understanding. We are grateful to many people who helped us in this effort, and we encourage further comment.

George Barnes, Paul Dabbs and others on the CDWR Planning Division staff ran the DWRSIM model through several iterations to reach Operation 144C that we felt could be used to illustrate our method of evaluating benefits and costs. CDFG biologists Frank Fisher, Richard Painter, Harry Rectenwald, David Hoopah and former CDFG biologist Richard Hallock all provided information about salmon runs in the Upper Sacramento River as did Fred Meyer and Pat O'Brien on the Lower American and Feather Rivers. David Dettman, now with the Monterey Peninsula Water Management District helped develop the Kjelson-Greene-Brandes and the Mitchell Model. Jack Rowell of the USBR provided

estimates of water temperature at various flows using a temperature model that he has developed for the Sacramento River. Dan Odenweller and Gary Smith of CDFG and Bill Mendehall of CDWR provided preliminary information from the Instream Flow Incremental Methodology study being done on the Upper Sacramento River.

We could not have developed the evaluation approach described in this report without the help of these professionals. We are grateful for their sharing knowledge and providing key information. They do not necessarily agree with our conclusions or all aspects of the approach taken, and they certainly are not responsible for errors we may have made in the work reported here.

Our first draft of this report was well critiqued by agency staffs and consultants to the water contractors. Especially helpful were Harold Meyer and George "Buzz" Link of Water Resources Management, Inc., Wayne Lifton of Entrix, Jim White of the CDFG, Marty Kjelson and Pat Brandes of the USFWS, Heidi Bratovich of the SWRCB, Randall Brown, Bob Suits and Jo Turner of the CDWR, Dave Vogel of CH2M HILL, members of EA Engineering, Science and Technology and Charles Hanson of Tenera. We are grateful to these professionals for taking the time to provide us with an unusually thorough and valuable peer review.

Many of our reviewers think there are too many uncertainties in some of the models and in using them sequentially. They believe that these uncertainties make the comparison between the two operations studies unreliable. Several offered to test and improve the models and we encourage that as a next step.

CHAPTER 2. A MODEL FOR CONVERTING DELTA SMOLT MORTALITY TO OCEAN HARVEST AND SPAWNING ESCAPEMENT OF FALL RUN CHINOOK SALMON FROM THE SACRAMENTO RIVER BASIN.

The model described in this chapter was designed to evaluate how changes in survival rates of smolts emigrating through the lower Sacramento River and Delta affect the long-term average ocean catch and spawning escapement of fall run chinook salmon. We believe this is necessary because the expression of Delta survival rates by themseves has little meaning to most of us. We wonder about the effect of smolt survival after they leave the Delta, the effect of fishing, the effects of different amounts and qualities of spawning and juvenile rearing habitat in the various rivers and the effect of mortality as the smolts migrate downstream to the Delta. Water agencies point to the large and successful salmon hatchery program and wonder how that can be factored in.

The Mitchell Salmon Production Model is an early attempt to consider these matters in as simple a way as possible. Two other models recently developed, one for the San Joaquin River system by EA Engineering and one for the Sacramento River System by Biosystems are much more detailed but require much data that is not yet available. The Mitchell Model is no substitute for them. Our hope is that it's use will demonstrate the need for research programs that will gather that data.

The model simulates the effect of natural production of salmon from the four major spawning areas in the Sacramento River basin --the American River, Feather River, Yuba River, and upper Sacramento River basin above the Feather River-- and of hatchery production from Nimbus, Feather River, and Coleman hatcheries. It was developed by William Mitchell, now with Jones and Stokes Associates, Inc. with assistance from Sheila Greene of the CDWR.

Predictions of natural production from each spawning area are based on Ricker spawner-recruit curves which relate the number of adult spawners (age 3 and older) to the average number of their progeny expected to survive to reach the Delta as emigrating smolts (Figures 2-1 through 2-4) assuming average environmental conditions in the river above the Delta. The great year-to-year variation in the data used to generate such curves reflects great differences in year-to-year survival rates from eggs deposited in the upstream river gravels to progeny reaching the Delta as smolts. Such variation is characteristic of data commonly used to develop spawner/recruit curves. In spite of this, they are based on sound biological principles (Ricker, 1954). Stock recruitment theory attributes such variation to mortality that is independent of stock size, while the curve itself is intended to reflect stock dependent mortality. We believe they are the best approach possible with existing data.

The spawner-smolt curves were developed for each spawning area from the 1965-1987 historical records of annual spawning escapement and age composition, estimates of ocean and inland catch, and ocean and inland recoveries of tagged hatchery salmon released as smolts in the Sacramento River system. Sources for these data include the CDFG, Pacific Fisheries Management Council (PFMC), and USFWS reports. Appendix A contains a description of how these curves were developed.

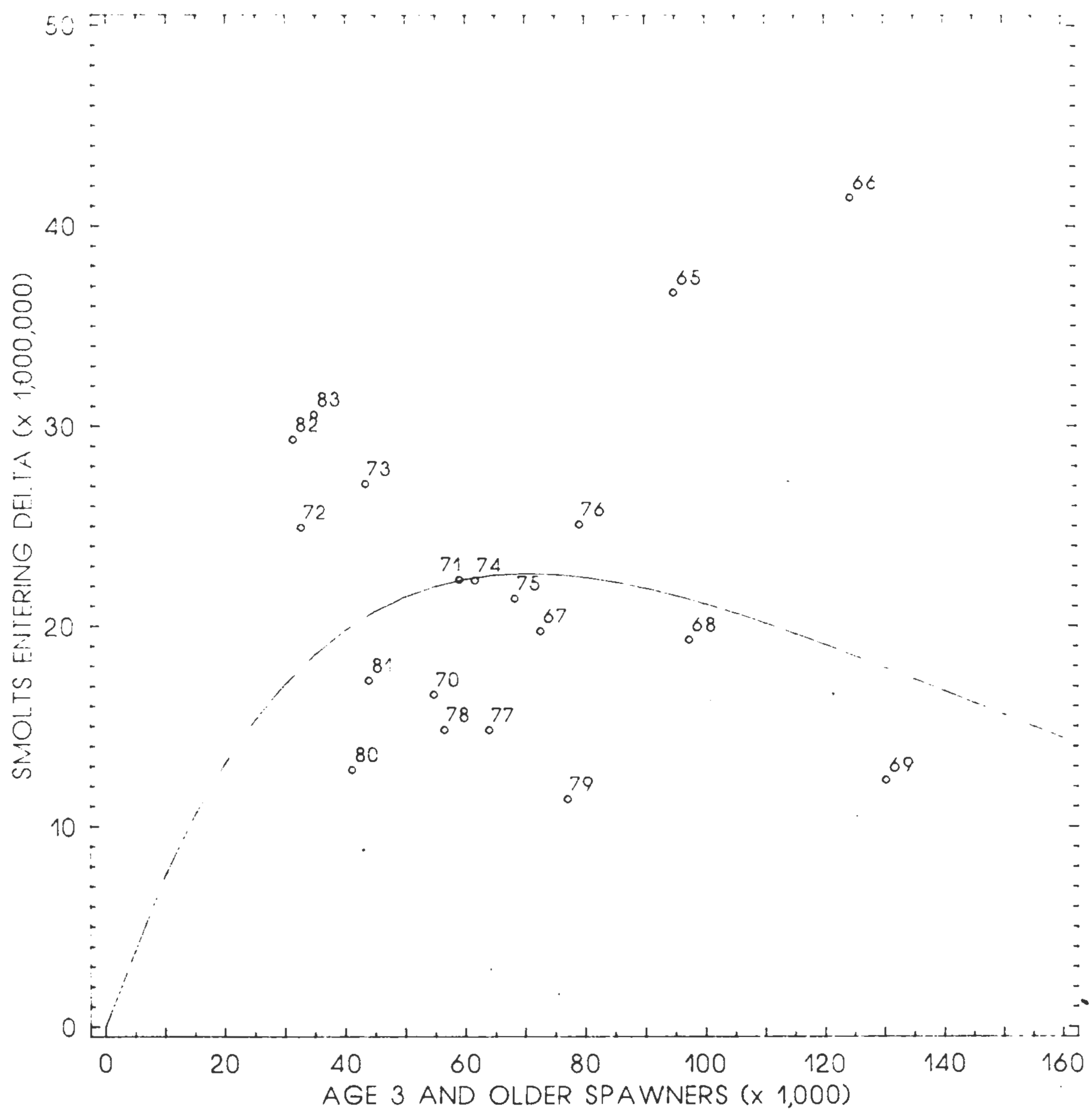

FIGURE 2-1. Spawner-smolt relation for natural production of fall chinook salmon in the upper Sacramento River basin (Sacramento River mainstem and minor tributaries, excluding Battle Creek), brood years 1965-1983. The Ricker curve describes the relation between the number of smolts entering the Delta and the number of adults in the spawning escapement. The curve is defined by the Ricker equation, $R = \alpha S e^{-\beta S}$, where R = recruits, in this case, smolts; S = adult spawners; $\alpha = 872.6$; and $\beta = 1.42 \times 10^{-5}$.

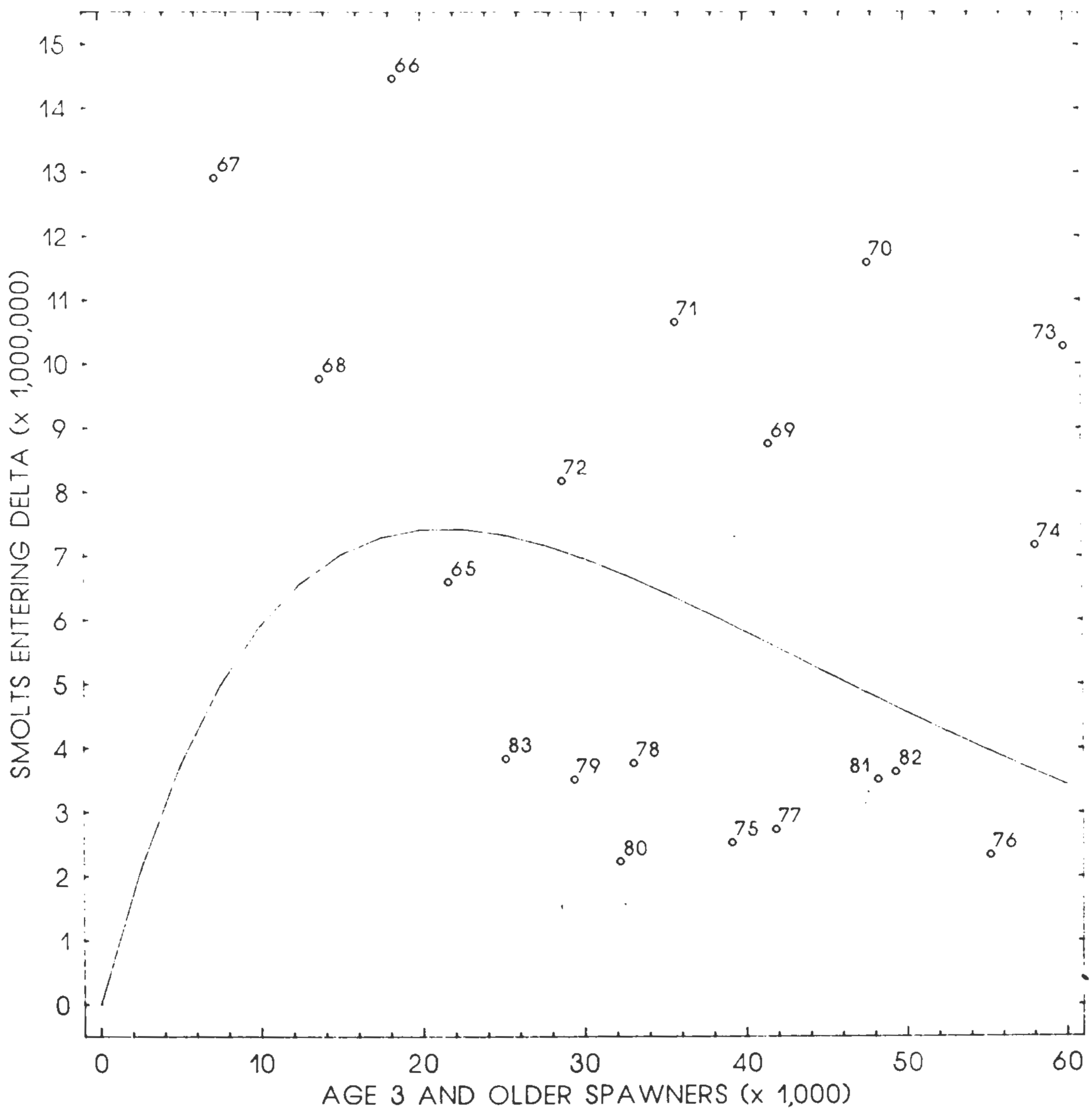

FIGURE 2-2. Spawner-smolt relation for natural production of fall chinook salmon in the Feather River, brood years 1965-1983. The Ricker curve describes the relation between the number of smolts entering the Delta and the number of adults that spawn naturally in the river. The curve is defined by the Ricker equation, $R = \alpha S e^{-\beta S}$, where R = recruits, in this case, smolts; S = adult spawners; $\alpha = 944.7$; and $\beta = 4.68 \times 10^{-5}$.

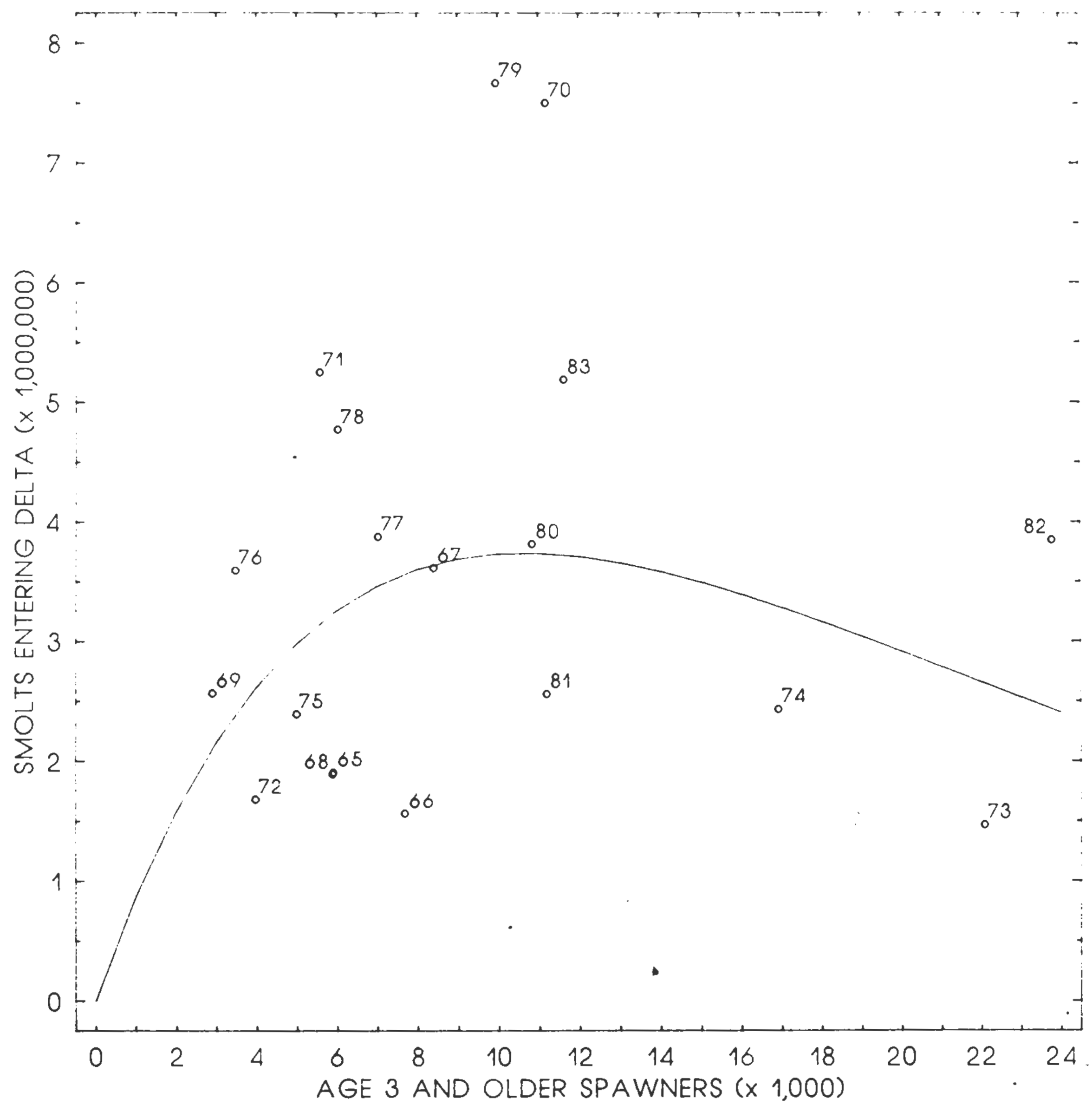

FIGURE 2-3. Spawner-smolt relation for natural production of fall chinook salmon in the Yuba River, brood years 1965-1983. The Ricker curve describes the relation between the number of smolts entering the Delta and the number of adults in the spawning escapement. the curve is defined by the Ricker equation, $R = \alpha Se^{-\beta S}$, where R = recruits, in this case, smolts; S = adult spawners; $\alpha = 954.1$; and $\beta = 9.40 \times 10^{-5}$.

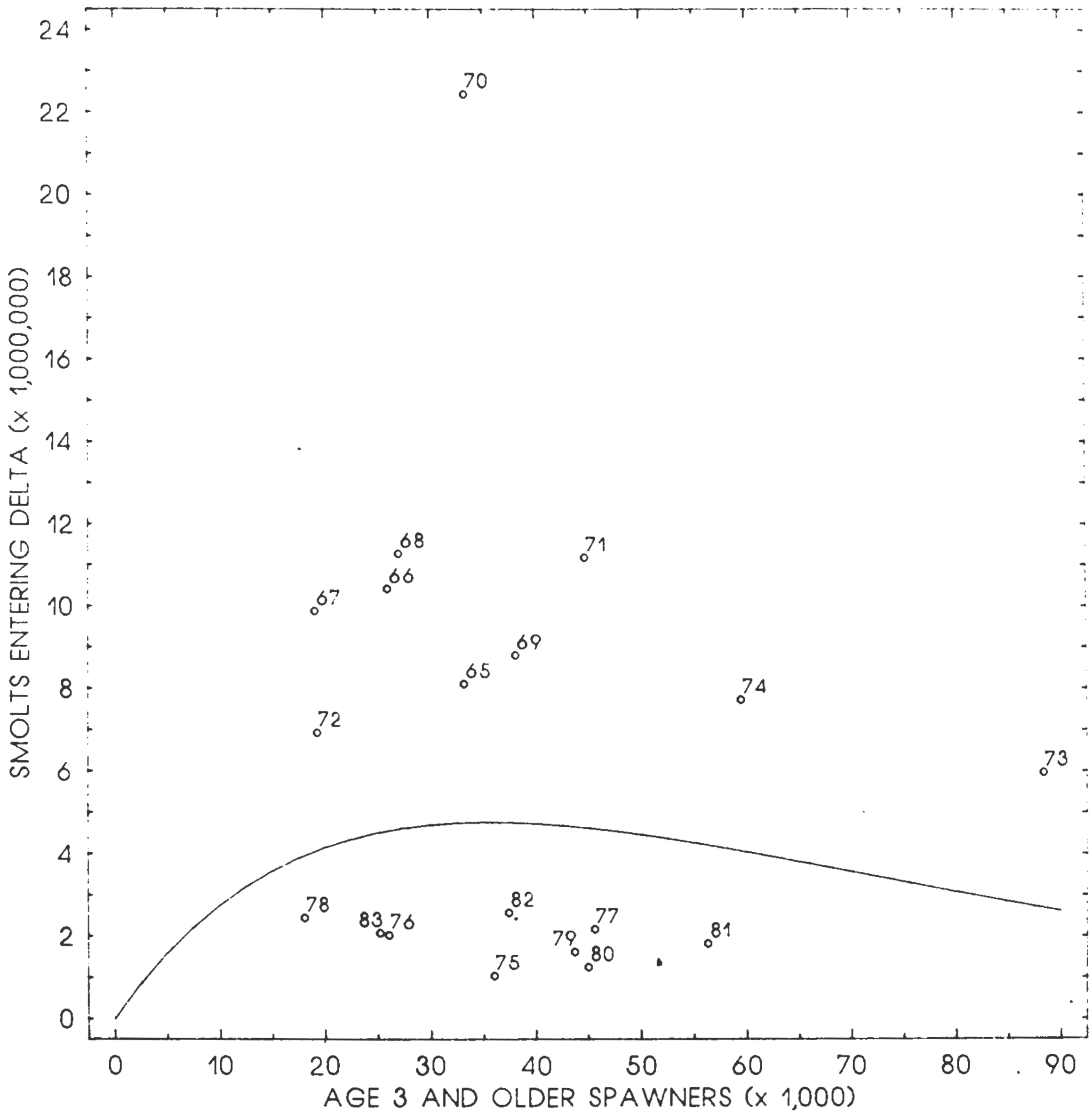

FIGURE 2-4. Spawner-smolt relation for natural production of fall chinook salmon in the lower American River, brood years 1965-1983. The Ricker curve describes the relation between the number of smolts entering the Delta and the number of adults that spawn naturally in the river. The curve is defined by the Ricker equation, $R = \alpha S e^{-\beta S}$, where R = recruits, in this case, smolts; S = adult spawners; $\alpha = 363.8$; and $\beta = 2.81 \times 10^{-5}$.

A spawner-smolt relation also was developed for Coleman Hatchery using a long-term record of the number of adult chinook spawned at the hatchery and the number of progeny planted as fingerlings and larger juveniles in Battle Creek and the upper Sacramento River (Figure 2-5). Production from Feather River and Nimbus hatcheries is represented in the model by the addition of the number of hatchery-produced smolts to the number of naturally-produced smolts leaving the Delta. This simulates the recent CDFG practice of planting most juvenile chinook produced at Feather and Nimbus hatcheries in the western Delta and bay, in order to prevent smolts from exposure to mortality through the Delta.

This model is most appropriately used to predict the effect of changes in smolt production and survival on long-term average levels of annual ocean harvest and spawning escapement. The model can also be used to determine equilibrium levels of annual harvest and escapement which will ultimately be reached if conditions do not change. It is inappropriate to use the model to predict annual fluctuations, but running averages encompassing several years can be used to illustrate probable trends over the years.

The first part of this chapter describes the structure and operation of the model. Appendix A describes in detail the data used to estimate the model parameters and how these estimates were used to develop the spawner-smolt curves.

OPERATION OF THE MODEL

Figure 2-6 illustrates the components of the model and, in a counterclockwise direction, the sequence of calculations performed by the model over the life of a single year class of chinook salmon born in year X (year class X). Similar calculations are performed for each major spawning stock in the Sacramento River basin. The basic differences are the forms of the spawner-smolt relations (Figures 2-1 through 2-5) and additional calculations performed for hatchery salmon.

A model run is started by entering the number of adults (ages 3, 4, and 5) spawning in year X (Figure 2-6). We start with the mean of CDFG's estimated spawning runs for 1983 through 1987. As illustrated in the Ricker curves, the SPAWNER-SMOLT relationships are then used to calculate the number of emigrating SMOLTS ENTERING THE DELTA the following spring, in year X+1.

The number of SMOLTS ENTERING THE DELTA is reduced by DELTA MORTALITY to calculate the number of SMOLTS LEAVING THE DELTA. The number of NIMBUS (American River) AND FEATHER RIVER HATCHERY SMOLTS is added to the number of SMOLTS LEAVING THE DELTA in order to simulate the planting of smolts in the western Delta or bay. The number of SMOLTS LEAVING THE DELTA is multiplied by the BAY/OCEAN MORTALITY rate to calculate the number of smolts that survive to AGE 3 ADULTS IN THE OCEAN at the beginning of the ocean fishing season in year X+3). The BAY/OCEAN MORTALITY includes the ocean catch of age 2 fish.

The number of AGE 3 ADULTS IN THE OCEAN is multiplied by the HARVEST RATE to calculate the OCEAN CATCH OF AGE 3 fish in year X+3. A certain fraction of the remaining fish will mature at the AGE 3 MATURITY RATE and

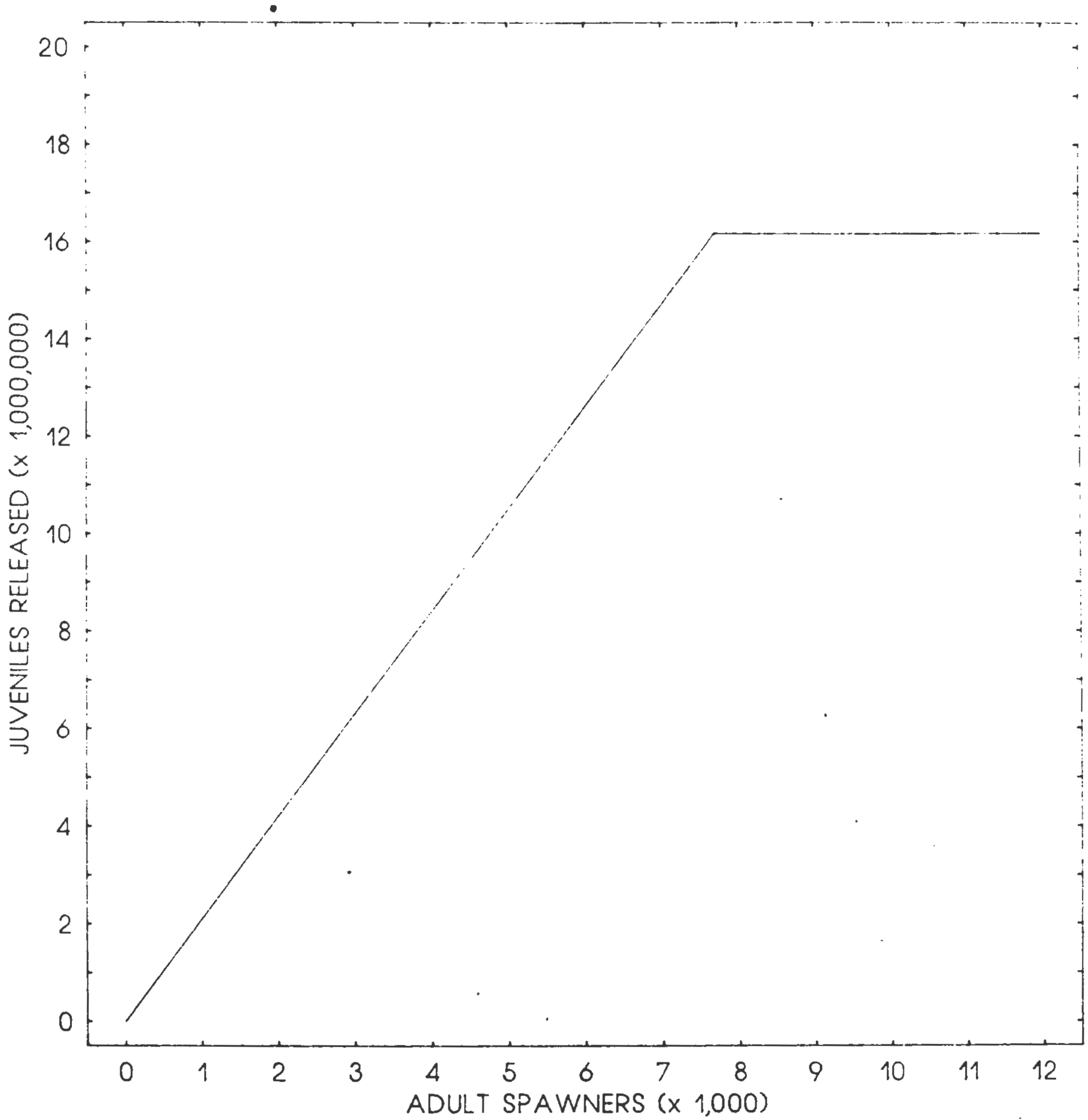

FIGURE 2-5. Relation used for calculating the number of fall chinook juveniles reared at Coleman Hatchery and released into Battle Creek and the upper Sacramento River, based on the number of adult spawners (ages 3-5) in the hatchery. The number of juveniles increases linearly with increasing adult spawners until 7,700 spawners is reached. At that point, the production capacity is met (approximately 16 million juveniles) and no further increases are possible.

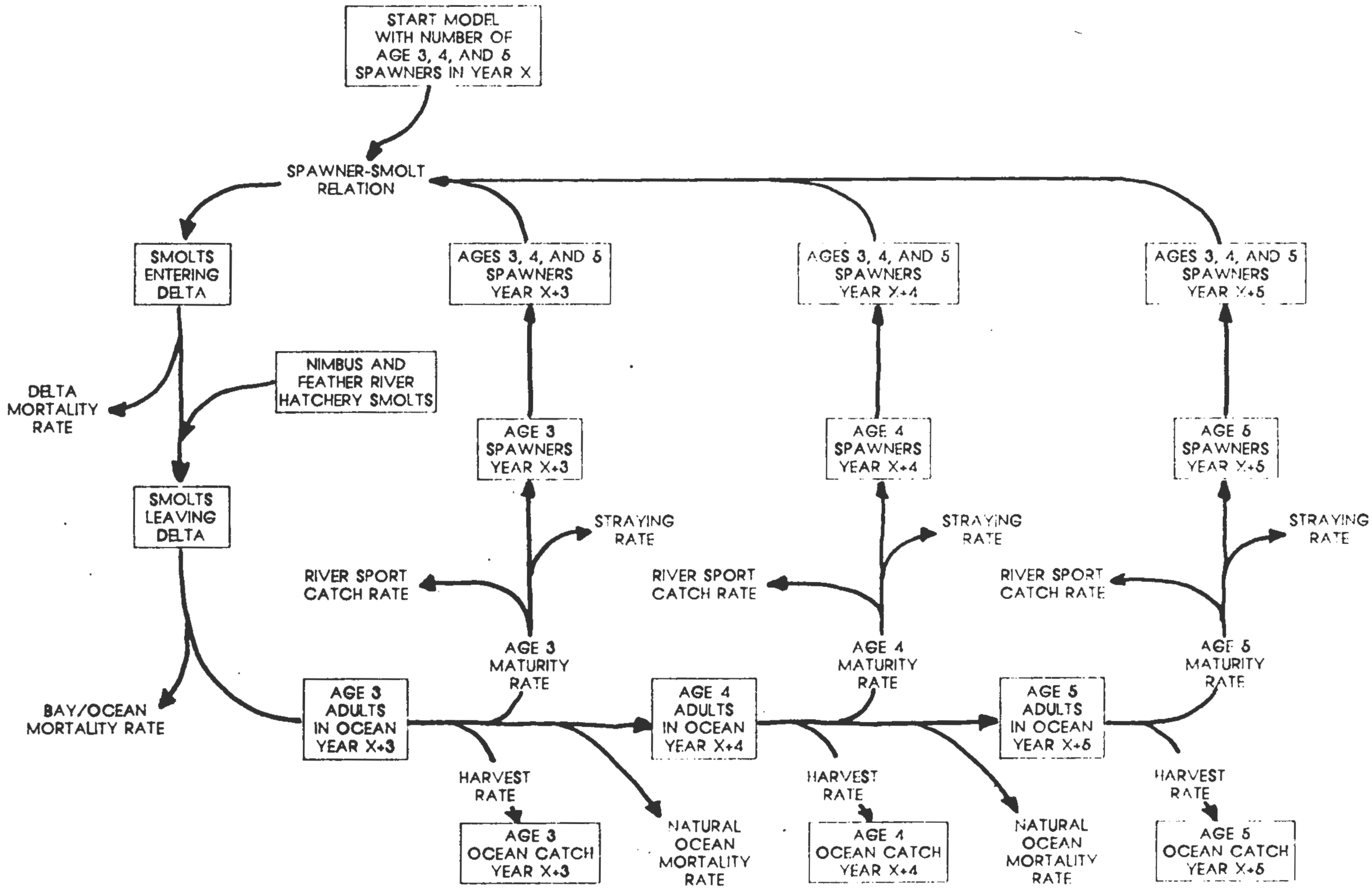

FIGURE 2-6. Components of the Salmon Production Model and, in a counterclockwise direction, the sequence of calculations performed by the model over the life cycle of a single year class of chinook salmon born in year X. The same calculations are performed for each major spawning stock in the Sacramento River basin. The basic differences are the forms of the spawner-smolt relations and additional calculations performed for hatchery salmon.

begin their return to fresh water. The other fraction remains in the ocean where they are subject to additional NATURAL OCEAN MORTALITY before becoming AGE 4 ADULTS IN OCEAN at the beginning of the fishing season in year X+4. The OCEAN HARVEST RATE in year X+4 and the AGE 4 MATURITY RATE determine the AGE 4 OCEAN CATCH and the number of age 4 fish that begin their return to fresh water. As before, the fish that remain in the ocean are reduced by NATURAL OCEAN MORTALITY to calculate the number of AGE 5 ADULTS IN OCEAN in year X+5. All age 5 fish that are not harvested are assumed to begin their return to fresh water in year X+5.

After the number of age 3 fish that return to fresh water in year X+3 is calculated, it is reduced by a RIVER SPORT CATCH RATE to calculate the number of AGE 3 SPAWNERS that reach the spawning grounds in year X+3. The number of AGE 3 SPAWNERS of year class X is then added to the number of AGE 4 AND 5 SPAWNERS of previous year classes X-1 and X-2 to form the spawning stock in year X+3. This total is entered into the spawner-smolt relationship to calculate the number of smolts entering the Delta to initiate a new year class X+3.

To simulate spawning in the following year (X+4), the age 4 fish from year class X are combined with age 3 (year class X+1) and age 5 (year class X-1) spawners. To simulate spawning in year X+5, age 5 fish from year class X are combined with age 3 (year class X+2) and age 4 (year class X+1) spawners.

Some additional calculations are performed for the American and Feather River spawning areas. The number of age 3 adults of both natural and hatchery origin that return to fresh water are calculated separately. The estimate of hatchery adults is reduced by a STRAYING RATE to calculate the number that return to their river of origin. The number of hatchery adults is added to the number of natural adults to calculate the total number of adults returning to fresh water. Adults of natural origin are assumed not to stray. The total is then reduced by a RIVER SPORT CATCH RATE to calculate the total adult spawning escapement. The number of age 3 adults that enter the hatchery is then subtracted to calculate the number that spawn in the river (calculations not shown in figure). These calculations are repeated for age 4 and 5 adults in succeeding years.

We use this model only to assess the effect of changing Delta survival rates which varies annually according to the Kjelson, Greene, Brandes Model. Functions describing the relationships between other life stages are either constants or a series of constants developed from historical data. If information were developed to explain the historical variation in the spawner-recruit relationships, it might be possible also to assess the affects of changing spawning or juvenile rearing habitat, reducing upstream diversions, etc. Such work is beyond the scope of this report or of the assigned work.

CHAPTER 3. SEQUENTIAL USE OF THE FOUR MODELS WITH OPERATION STUDY 75D

Our goal in this chapter is to describe the sequential use of four models. We do this using a "baseline" operation study (75D) prepared by the CDWR for the Delta Hearings. The four models used are :

1. The DWRSIM model which calculates reservoir storage, river flow, and water deliveries for the SWP/CVP.
2. The USBR water temperature model developed by Jack Rowell to calculate reservoir and river temperatures (Rowell, 1990).
3. The USFWS Delta Smolt Survival model developed by Kjelson, Greene and Brandes to calculate the mortality rate of salmon smolts passing through the Delta on their way to sea in the spring (Kjelson, et al., 1989).
4. The Mitchell Salmon Production Model to convert smolt mortality rate to long-term averages of ocean catch and spawning escapement.

THE DWRSIM MODEL

The DWRSIM model is used by the CDWR for planning. The model simulates operation of the SWP and the CVP in the Trinity and Sacramento basins. Output consists of the end-of-month volume of reservoir storage in federal and state reservoirs in those basins and the monthly flows at many locations in rivers and diversions. The baseline study used in this report is the 75D Operation with DWR's estimate of 1990 hydrology, 1990 CVP and SWP demands, existing reservoir and transport facilities, and existing laws, regulations, and policies to protect instream uses both above and in the Delta. The model was run using the 1922 through 1978 water years. Since the beginning of this effort, CDWR has submitted revised "baseline" studies to the CSWRCB, but 75D will serve to illustrate the approach. Table 3-1 lists the mean monthly flows calculated by Operation Study 75D for the Sacramento River at Freeport, 12 miles below Sacramento.

USBR'S WATER TEMPERATURE MODEL

USBR's temperature model of the Sacramento basin (Rowell, 1990) applies mean monthly historical weather conditions to monthly storage levels in all the major reservoirs and calculates heat losses and gains as the reservoir water and accretion passes down the rivers below those reservoirs into the Delta. For this baseline evaluation, we use USBR's estimate of mean monthly spring temperatures at Freeport as input to the Kjelson, et al., model which calculates the survival rate of smolts passing through the Delta on the basis of water temperature and two other parameters. USBR's estimates for the 75D Study assumes that an effective water temperature control device has been installed in Shasta Reservoir. Table 3-2 describes USBR's estimates of the mean monthly April, May and June water temperatures of the Sacramento River at Freeport for the 57-year period of the operation study.

THE KJELSON, ET AL., DELTA SMOLT SURVIVAL MODEL

The Kjelson, Greene and Brandes Delta Smolt Survival model calculates the mortality of smolts passing through the Delta on the basis of water

TABLE 3-1. Simulated mean monthly Sacramento River flows in the vicinity of Sacramento of DWRSIM Operation Study 75D.

****
* CP 44 + 50 SACRAMENTO RIVER AT SACRAMENTO *
****

RIVER FLOW---CFS

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1922	10744	12002	16601	13266	37268	22231	17222	38779	19431	20254	17825	11546
1923	12194	18936	35888	24832	16502	14940	20338	15839	15955	19015	15157	11584
1924	11558	15189	14339	13983	15087	10154	10764	10884	11893	12183	7593	7360
1925	8466	10485	12051	13814	31378	20703	21406	18317	17604	18238	11608	10406
1926	10835	10155	13557	14329	38107	15356	17577	13132	13906	15955	11332	9779
1927	10585	19538	16813	26723	87462	33505	47523	30253	19837	21847	20121	9796
1928	13244	18004	16857	17690	25933	82890	22544	13490	15333	21163	17962	10348
1929	15331	13606	13138	13398	14822	13048	16064	10181	11049	15847	12149	10266
1930	9987	11324	15767	18833	13872	25876	17553	12970	14679	16454	11635	10503
1931	10360	11189	15907	13521	13539	12377	11674	10499	11711	11788	7576	7332
1932	7375	11107	12338	18136	13309	11987	13738	13477	14400	12589	9140	9287
1933	8967	8348	13189	11713	14107	14043	9452	9778	11610	10320	7558	7352
1934	7313	12365	14164	14095	10462	11862	9116	10031	11152	10265	7709	8849
1935	7962	12676	13934	23334	19527	19110	19483	20815	17234	17097	11245	9529
1936	11643	10561	13928	23468	40026	26934	19129	20682	17215	20471	19064	9590
1937	14150	15571	13644	11042	29455	34721	19035	17984	15614	18963	11741	9681
1938	12689	20597	51058	26825	77986	74007	43263	61237	35094	16196	13861	15223
1939	19884	22279	13746	12244	11475	11713	13467	10412	11640	16270	11590	10165
1940	10404	14718	16041	18550	42444	61549	37073	16978	17467	20540	19873	9484
1941	14305	15578	22787	69920	73163	50562	45472	47829	19364	21847	17146	9916
1942	14113	22788	57559	63560	76424	18300	43014	42840	28502	21668	18708	9569
1943	12516	24224	26438	54732	49035	59962	26252	21979	20240	21994	18855	9415
1944	14298	15319	14706	13152	22769	18342	15299	12125	13604	16750	11009	9467
1945	11305	13898	13822	12156	38767	19360	15814	16961	15182	18613	17293	9761
1946	12277	15914	58999	41581	17107	15137	15052	17547	18005	20877	17701	9973
1947	14343	13606	13100	13326	15241	17584	15408	13418	13907	16520	11388	9917
1948	11738	11214	15986	15456	15682	20372	22092	26654	21119	21345	18343	11135
1949	15841	15488	14650	13891	14212	43824	14538	14276	14057	14978	11560	10855
1950	10772	10741	15256	16519	29209	20778	17432	19762	16224	19380	19437	11808
1951	13092	47008	68867	54330	56045	23981	17791	21059	15098	21059	20761	11151
1952	14123	14100	45421	63134	64052	51080	56437	66474	39061	18720	13749	17034
1953	23393	21368	38489	60143	21352	17379	18574	32158	29162	22400	18242	11470
1954	14994	26074	15688	26099	52269	43249	40305	20136	18392	21111	18007	10844
1955	15587	14582	24376	17848	13558	15552	17284	13401	13845	17681	11530	11331
1956	13568	15394	36312	74976	61892	28542	20063	48563	23711	21977	19270	11481
1957	16139	21642	13401	13009	28115	40224	18283	19806	16711	19723	19637	12809
1958	18385	17695	26234	36731	61894	90445	50724	48122	34718	21945	18165	13712
1959	17813	21057	12689	29504	45976	15336	15595	13668	14099	18952	13303	12494
1960	10703	12784	16205	14088	22370	21030	18869	13360	14731	19359	12073	11124
1961	10565	11923	16199	12893	24576	15302	18814	13214	14076	17528	11498	10933
1962	10398	11637	15326	15239	34202	21526	18113	16109	17410	19716	15828	11556
1963	25778	23204	29544	16662	60728	23418	69962	34597	21064	22563	20178	11014
1964	15696	22974	14252	20654	15237	15424	18638	13515	13654	15010	11626	10721
1965	10840	14002	38907	73038	29418	18388	43184	24439	19518	21782	19444	10642
1966	10828	21719	16103	27758	24631	22988	16397	12616	14809	19686	15199	10794
1967	14747	13659	35787	39319	39401	47473	38995	51237	41929	16623	13583	16984
1968	22416	22148	16184	21915	56346	27499	14608	12908	14774	19719	14427	11615
1969	15463	14272	19338	70548	65303	36799	44587	50990	25208	14189	14462	18195
1970	21666	22929	42718	92343	48643	30204	17363	12623	15177	21262	15451	10949
1971	13229	19388	60213	46407	24902	46449	18621	33212	24902	22579	19965	11849
1972	16581	22303	20239	15933	19703	24019	20101	12976	14560	19321	18284	11510
1973	13593	17491	25059	51155	68608	39912	17085	20108	21786	22238	15382	11594
1974	13619	52609	58395	77355	40896	92118	33977	30946	21936	21766	19475	14770
1975	17660	23260	19118	13863	52839	68798	21691	35260	24453	20416	17561	14951
1976	22472	24411	15395	12450	14361	13127	16543	10864	11592	14913	12185	11483
1977	10581	10020	10262	10650	9862	7583	8141	8872	9753	10612	8589	6970
1978	5810	8990	13726	34503	43011	45883	39029	25124	18957	18838	14535	13499
AVG.	13595	17475	23697	29590	35168	30613	23975	22903	18388	18441	14887	11112

TABLE 3-2. USBR's estimate of mean monthly spring water temperature of the Sacramento River at Freeport using DWRSIM Operation Study 75D and historical weather conditions. These estimates assume that an effective water temperature control device has been installed in Shasta Reservoir.

YEAR	APRIL	MAY	JUNE	YEAR	APRIL	MAY	JUNE
1922	58.5	61.3	65.9	1950	61.4	64.4	69.0
1923	58.3	62.5	65.5	1951	60.0	64.5	70.4
1924	61.6	69.2	70.6	1952	56.3	61.7	65.0
1925	59.1	63.2	68.5	1953	59.0	61.0	66.3
1926	61.6	65.8	71.3	1954	58.9	65.9	68.7
1927	57.2	62.6	68.1	1955	57.0	67.0	70.1
1928	58.8	66.7	69.7	1956	59.8	61.5	68.7
1929	57.0	66.2	70.2	1957	60.8	64.1	72.0
1930	59.7	63.2	69.7	1958	57.5	62.9	67.7
1931	63.0	70.5	70.4	1959	63.2	65.9	72.0
1932	59.1	65.4	69.4	1960	59.8	66.0	72.8
1933	60.2	63.6	69.8	1961	60.4	64.4	73.3
1934	63.8	68.3	70.6	1962	61.9	64.8	70.5
1935	58.9	64.0	71.0	1963	54.6	62.5	69.0
1936	59.7	64.9	69.2	1964	59.5	65.3	69.6
1937	58.8	64.6	69.9	1965	57.4	63.6	67.1
1938	56.5	62.5	67.7	1966	62.2	67.4	70.5
1939	63.6	68.1	71.1	1967	54.2	62.1	66.5
1940	57.4	65.6	71.6	1968	61.7	66.2	72.0
1941	57.3	61.6	68.9	1969	57.1	63.3	68.3
1942	56.7	60.2	67.8	1970	59.0	68.6	70.7
1943	59.0	65.4	66.6	1971	58.8	61.2	68.1
1944	58.6	66.0	67.9	1972	59.1	67.3	70.8
1945	60.6	63.2	70.7	1973	61.4	67.0	70.3
1946	60.8	64.0	68.2	1974	56.8	63.4	69.7
1947	62.6	68.8	70.1	1975	56.8	63.9	69.2
1948	56.7	62.3	69.0	1976	59.1	69.6	71.8
1949	61.9	65.3	71.2	1977	64.4	64.0	73.8
				AVG.	59.4	64.7	69.5

temperatures of the Sacramento River at Freeport, fraction of the Sacramento River diverted into the interior Delta at Walnut Grove via the Delta Cross Channel and Georgiana Slough, and the rate of SWP plus CVP export pumping. Based on 12 years of planting and recovering marked salmon smolts, Kjelson, et al., developed an understanding of how temperature and export diversion rate affects the survival of smolts emigrating down three reaches of the Delta (Figure 3-1), (1) from Sacramento downstream to Walnut Grove, just above the USBR Delta Cross Channel which diverts Sacramento River water into the interior Delta; (2) from Walnut Grove into the Delta Cross Channel and Georgiana Slough down the Mokelumne River into the interior Delta, the lower San Joaquin River, and finally to Chipps Island; and, (3) from Walnut Grove just below Georgiana Slough directly down the Sacramento River to Chipps Island via the main Sacramento River channel. In the model, mortality through Reach 1 is very sensitive to water temperatures -- being 0 at 59°F, and 100% at 80°F. Mortality in Reach 2 is always high, even at low temperatures and exports. Mortality in the broad Reach 3 of major tidal influence is sensitive to temperature, but is less so than in Reach 1 (Figure 3-2). Obviously, for a salmon smolt, continuing directly down the Sacramento River is better than entering the Delta Cross Channel or Georgiana Slough.

To apply this model, we assume that the fraction of smolts taking the less desirable route through the interior Delta and lower San Joaquin River systems to Chipps Island is equivalent to the monthly fraction of the Sacramento River water diverted out of the Sacramento River via the Delta Cross Channel and Georgiana Slough. Since the DWRSIM model does not simulate this diversion, we have calculated it according to the following rules and equations.

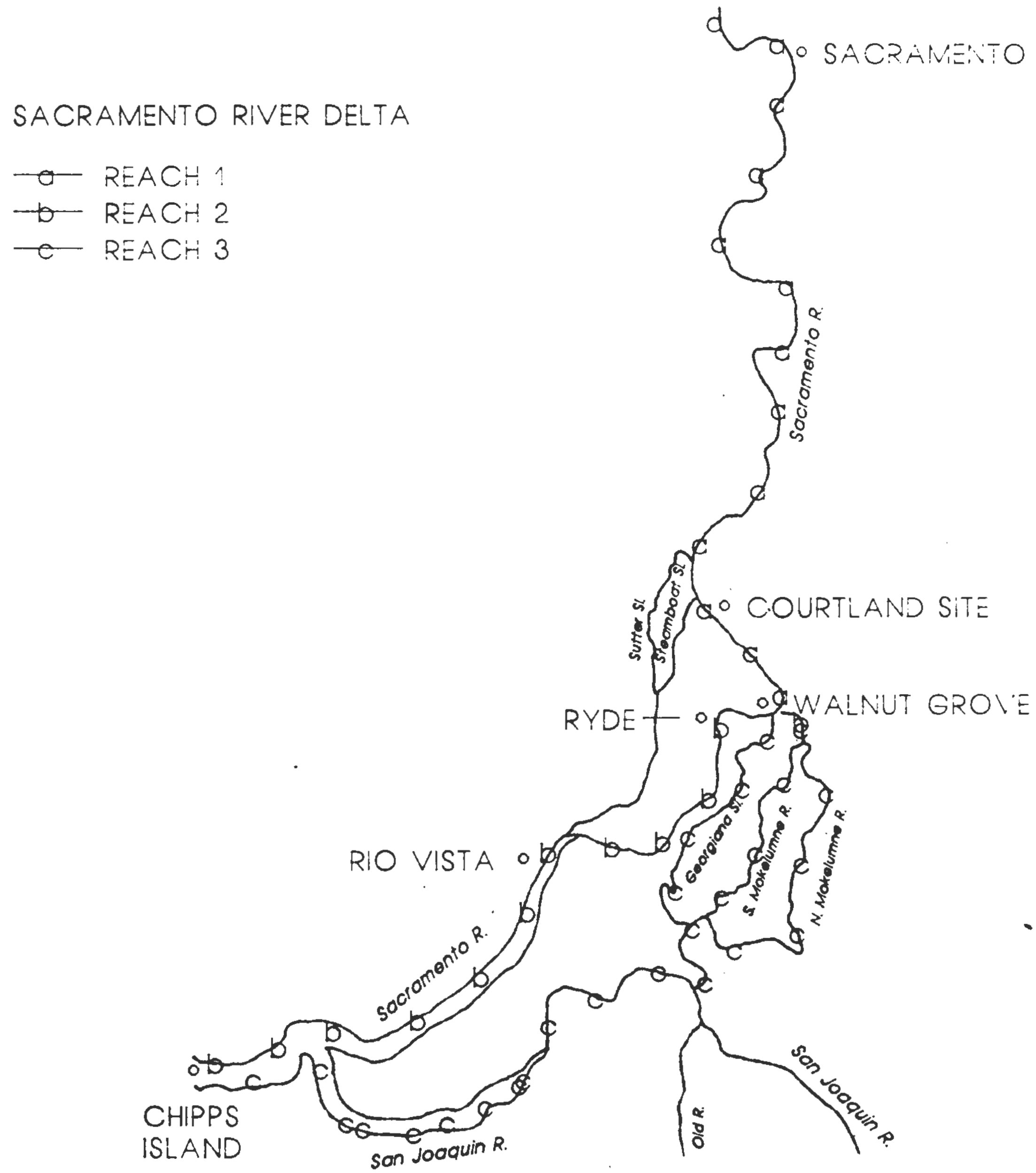

FIGURE 3-1. Map of the Delta showing the three reaches for which mortality of emigrating smolts is calculated using water temperature, diversions and exports. Reach 1 : Sacramento to Walnut Grove; Reach 2 : Walnut Grove to Chipps Island via the Mokelumne and lower San Joaquin River systems; Reach 3 : Walnut Grove to Chipps Island via the Sacramento River system.

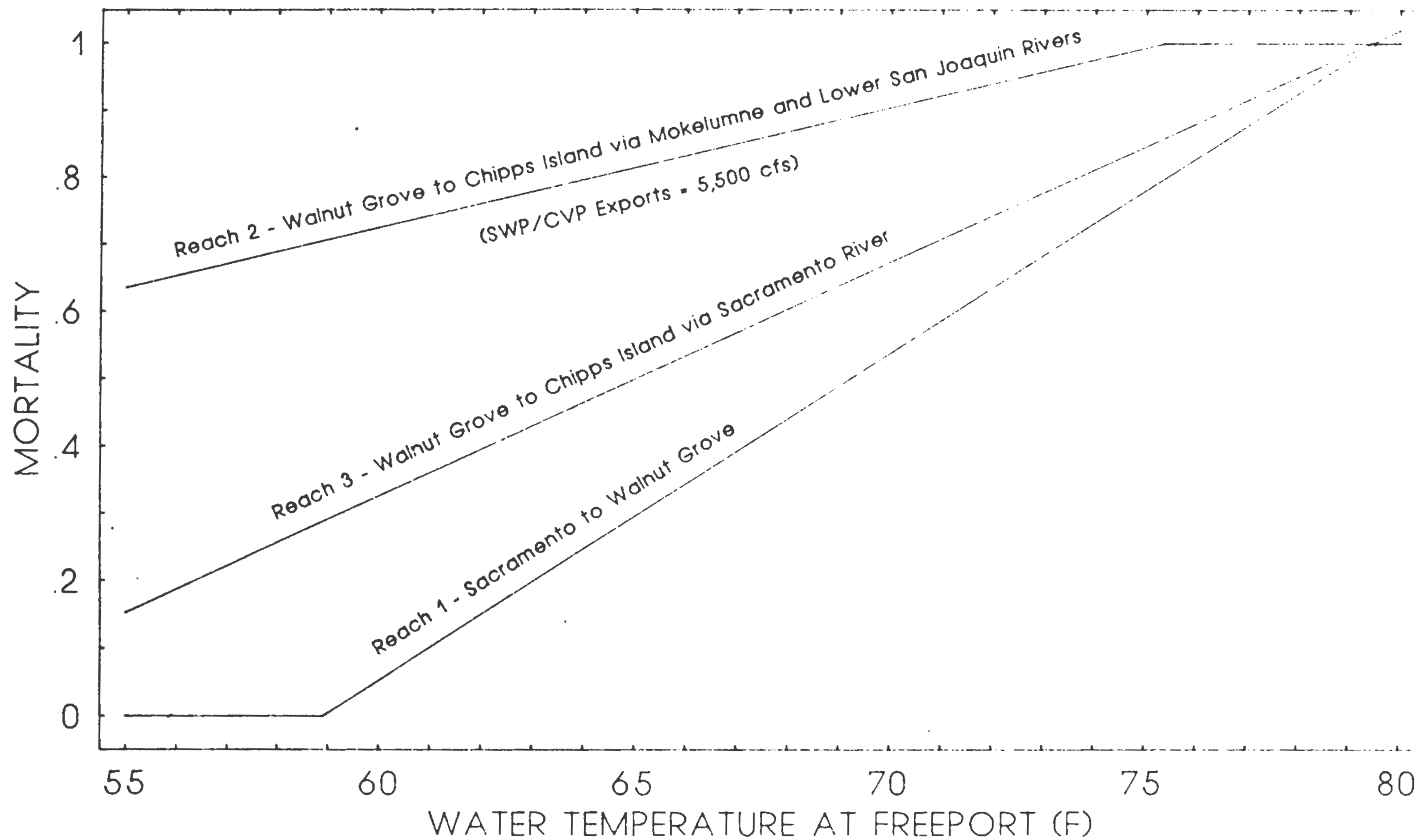

FIGURE 3-2. Relation between salmon smolt mortality and water temperature in 3 reaches of the Sacramento-San Joaquin Delta used in the Kjelson, Greene and Brandes Smolt Survival Model (Kjelson, et al., 1989).

January - May

If QOUT > 12,000 cfs - Close Cross Channel Gates
If QOUT ≤ 12,000 cfs - Open Cross Channel Gates

June - December

If QSAC > 25,000 cfs - Close Cross Channel Gates
If QSAC ≤ 25,000 cfs - Open Cross Channel Gates

When Gates are Closed

$$QXGEO = (QSAC * 0.133) + 829$$

When Gates are Open

$$QXGEO = (QSAC * 0.293) + 2090$$

Diversion Fraction

$$DIV = QXGEO/(QSAC * 0.626 + 950)$$ [1]

where: QOUT = Net Delta Outflow; QXGEO = Flow in Delta Cross Channel plus Georgiana Slough; and QSAC = Sacramento River flow at Freeport.

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[1] (QSAC * 0.626 + 950) represents the estimate of the Sacramento River flow below Steamboat and Sutter Sloughs and above the Delta Cross Channel and Georgiana Slough.

These rules and equations represent our understanding of current criteria and flow relationships governing the operation of the Delta Cross Channel. Estimates of the fractions of the Sacramento River water (and salmon) being directed into the Mokelumne system via the Cross Channel and Georgiana Slough in each April, May, and June of the 57-year period with Operation 75D are listed in Table 3-3.

The Kjelson, et al., model calculates mortality of smolts emigrating through the Delta by applying the equations that relate mortality to temperature in, and exports from each reach to whatever portion of the emigrants is using that reach.

Mortalities are calculated separately for each April, May, and June of the 57-year operation study because, obviously, temperatures, exports and fractions diverted are different in each month (Table 3-4). To calculate the total annual mortality for each year we assumed that 15% of the emigration would occur in April, 55% in May, 20% in the first half of June and 10% in the last half of June and weighted the mortality estimates accordingly. These proportions are based on David Dettman's examination of USFWS data on the migration time of juveniles passing Red Bluff Diversion Dam and Chipps Island in recent years (Appendix B). As Dettman points out, timing varies from year to year, but with existing data we are unable to define the causes of that variation or to develop a way to estimate how different operations would affect it. We understand that analysis of more recent data is evidence that these percentages have shifted lower in June and higher in April. The new data can be incorporated into future model runs.

THE MITCHELL SALMON PRODUCTION MODEL

This salmon population model estimates how the mortality suffered by fall run smolts as they emigrate from the Sacramento River basin through the Delta in the spring affects ocean catch and spawning escapement. Although it calculates population dynamics on an annual basis, single year estimates of catch and escapement are not reliable. There are many reasons for this. First, the relationship between the number of spawners and the number of smolts entering the Delta varies greatly from year to year, but we use the relationships illustrated by the curves (as illustrated in the scatter of data points around the curves in Figures 2-1 through 2-4) themselves. Second, the proportions of smolts that emigrate down in April, May, and June are different from year to year, but we use the same average proportion for each year. Finally, the natural ocean mortality of smolts and adults varies from year to year, but we use a single average for each year. For these reasons we have calculated 5-year running averages to illustrate trends and the average ocean catch and spawning escapements for longer periods.

BASELINE ESTIMATES OF CATCH AND ESCAPEMENT

Estimates of Delta smolt mortality, calculated with the Kjelson, et al., model for each spring of the 57-year Operation Study 75D (Table 3-4), were entered into the Mitchell Model. Figures 3-3 through 3-6 illustrate the resulting 5-year running averages of predicted annual ocean catches that resulted from a combination of natural and hatchery production in each of the

TABLE 3-3. Percent of the Sacramento River water diverted out of the Sacramento River and into the Mokelumne and lower San Joaquin Rivers system via the Delta Cross Channel and Georgiana Slough using results of DWRSIM Operation Study 75D.

YEAR	APRIL	MAY	JUNE	YEAR	APRIL	MAY	JUNE
1922	0.266	0.237	0.593	1950	0.607	0.260	0.616
1923	0.258	0.619	0.618	1951	0.604	0.257	0.626
1924	0.682	0.680	0.664	1952	0.230	0.227	0.237
1925	0.256	0.263	0.606	1953	0.599	0.242	0.245
1926	0.606	0.648	0.638	1954	0.236	0.259	0.600
1927	0.233	0.244	0.591	1955	0.608	0.644	0.639
1928	0.254	0.643	0.624	1956	0.259	0.232	0.572
1929	0.618	0.693	0.677	1957	0.601	0.259	0.612
1930	0.606	0.649	0.630	1958	0.232	0.233	0.240
1931	0.667	0.687	0.667	1959	0.622	0.641	0.636
1932	0.640	0.643	0.633	1960	0.597	0.645	0.630
1933	0.708	0.701	0.668	1961	0.597	0.647	0.637
1934	0.715	0.696	0.676	1962	0.602	0.617	0.607
1935	0.260	0.257	0.608	1963	0.226	0.240	0.584
1936	0.595	0.258	0.608	1964	0.598	0.643	0.641
1937	0.261	0.264	0.621	1965	0.235	0.251	0.593
1938	0.235	0.228	0.240	1966	0.615	0.654	0.629
1939	0.643	0.688	0.668	1967	0.237	0.231	0.236
1940	0.238	0.267	0.607	1968	0.631	0.650	0.629
1941	0.234	0.233	0.594	1969	0.234	0.232	0.250
1942	0.235	0.235	0.246	1970	0.607	0.654	0.626
1943	0.249	0.255	0.589	1971	0.599	0.241	0.568
1944	0.624	0.661	0.642	1972	0.590	0.649	0.632
1945	0.620	0.267	0.625	1973	0.609	0.259	0.581
1946	0.627	0.265	0.603	1974	0.241	0.243	0.580
1947	0.623	0.644	0.638	1975	0.256	0.240	0.569
1948	0.255	0.248	0.584	1976	0.614	0.680	0.668
1949	0.632	0.634	0.637	1977	0.740	0.721	0.701
				1978	0.237	0.250	0.596
				AVG.	0.465	0.435	0.575

TABLE 3-4. Estimated monthly and weighted yearly Delta smolt survival for years 1922-1977 using DWRSIM Operation Study 75D.

YEAR	APRIL	MAY	JUNE	WEIGHTED TOTAL
1922	0.57	0.47	0.18	0.40
1923	0.56	0.29	0.21	0.31
1924	0.30	0.10	0.07	0.12
1925	0.54	0.37	0.13	0.32
1926	0.23	0.19	0.06	0.16
1927	0.62	0.40	0.14	0.36
1928	0.55	0.15	0.10	0.20
1929	0.38	0.18	0.08	0.18
1930	0.30	0.28	0.09	0.23
1931	0.23	0.08	0.08	0.10
1932	0.39	0.19	0.10	0.19
1933	0.35	0.25	0.09	0.22
1934	0.24	0.12	0.08	0.13
1935	0.55	0.33	0.07	0.29
1936	0.30	0.29	0.11	0.24
1937	0.56	0.30	0.09	0.28
1938	0.66	0.42	0.19	0.39
1939	0.21	0.12	0.07	0.12
1940	0.60	0.27	0.06	0.26
1941	0.62	0.46	0.10	0.38
1942	0.63	0.54	0.19	0.45
1943	0.57	0.27	0.18	0.29
1944	0.36	0.19	0.13	0.20
1945	0.26	0.37	0.08	0.27
1946	0.25	0.33	0.13	0.26
1947	0.23	0.12	0.09	0.13
1948	0.62	0.42	0.10	0.35
1949	0.25	0.19	0.06	0.16

YEAR	APRIL	MAY	JUNE	WEIGHTED TOTAL
1950	0.23	0.32	0.11	0.24
1951	0.30	0.31	0.08	0.24
1952	0.66	0.45	0.29	0.43
1953	0.37	0.49	0.24	0.40
1954	0.56	0.26	0.12	0.26
1955	0.39	0.15	0.09	0.17
1956	0.51	0.46	0.11	0.36
1957	0.25	0.33	0.05	0.23
1958	0.61	0.39	0.19	0.36
1959	0.22	0.19	0.05	0.15
1960	0.30	0.19	0.04	0.16
1961	0.28	0.24	0.03	0.18
1962	0.22	0.23	0.08	0.18
1963	0.72	0.41	0.12	0.37
1964	0.31	0.21	0.10	0.19
1965	0.60	0.35	0.16	0.33
1966	0.21	0.15	0.08	0.14
1967	0.73	0.44	0.24	0.42
1968	0.26	0.18	0.05	0.15
1969	0.65	0.38	0.17	0.36
1970	0.39	0.12	0.08	0.15
1971	0.35	0.47	0.13	0.35
1972	0.35	0.15	0.07	0.16
1973	0.27	0.21	0.09	0.18
1974	0.62	0.36	0.09	0.32
1975	0.63	0.35	0.10	0.32
1976	0.32	0.09	0.05	0.11
1977	0.23	0.26	0.04	0.19
AVG.	0.42	0.28	0.11	0.25

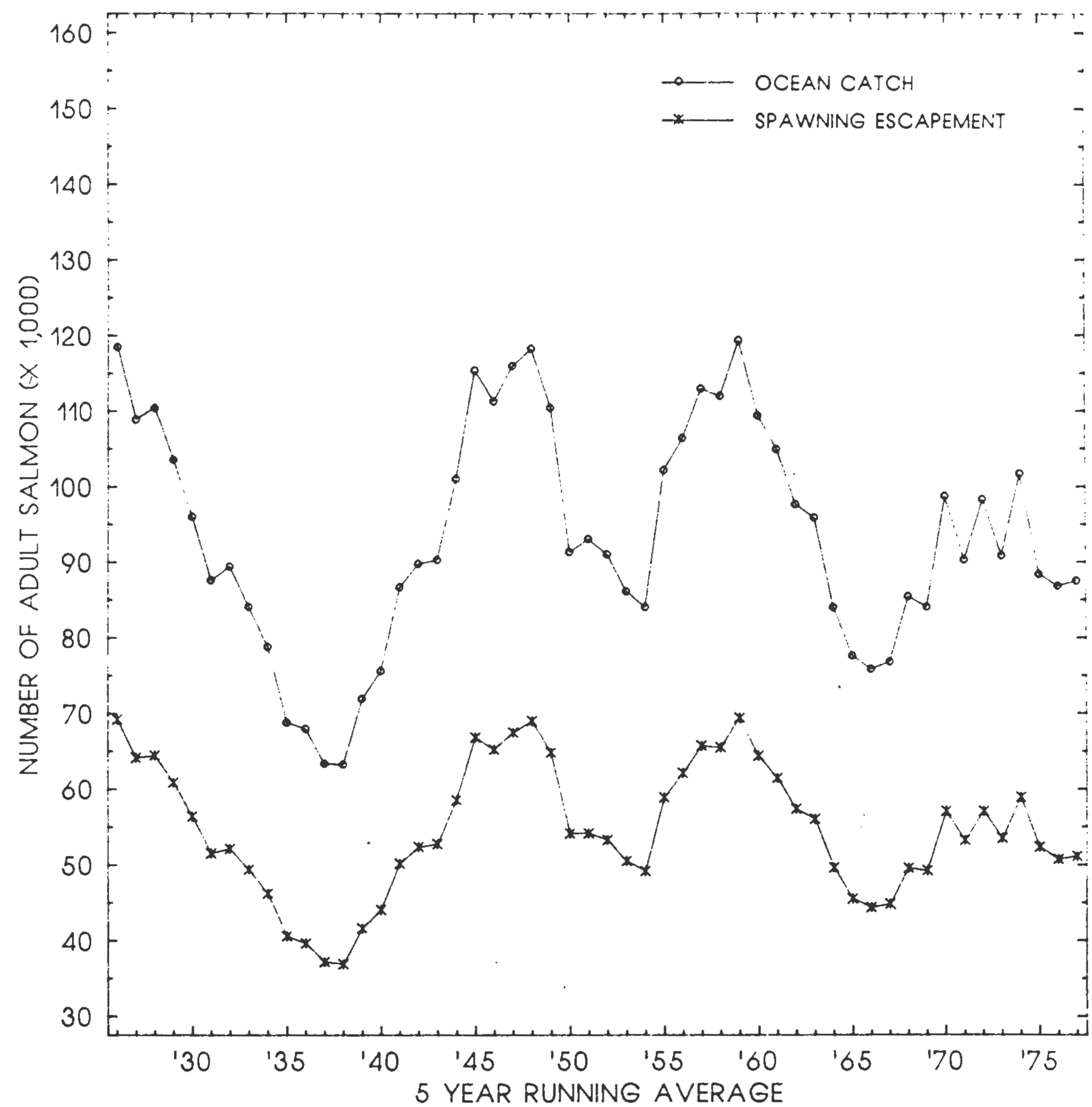

FIGURE 3-3. Mitchell predicted five-year running averages of estimated annual ocean catch and spawning escapement of adult (ages 3, 4 and 5) fall run chinook salmon from the upper Sacramento River basin, based on estimated delta smolt mortality from years 1922-1978 of DWRSIM Operation Study 75D. Estimates represent natural production from the Sacramento River mainstem and minor tributaries above the Feather River confluence, excluding Battle Creek.

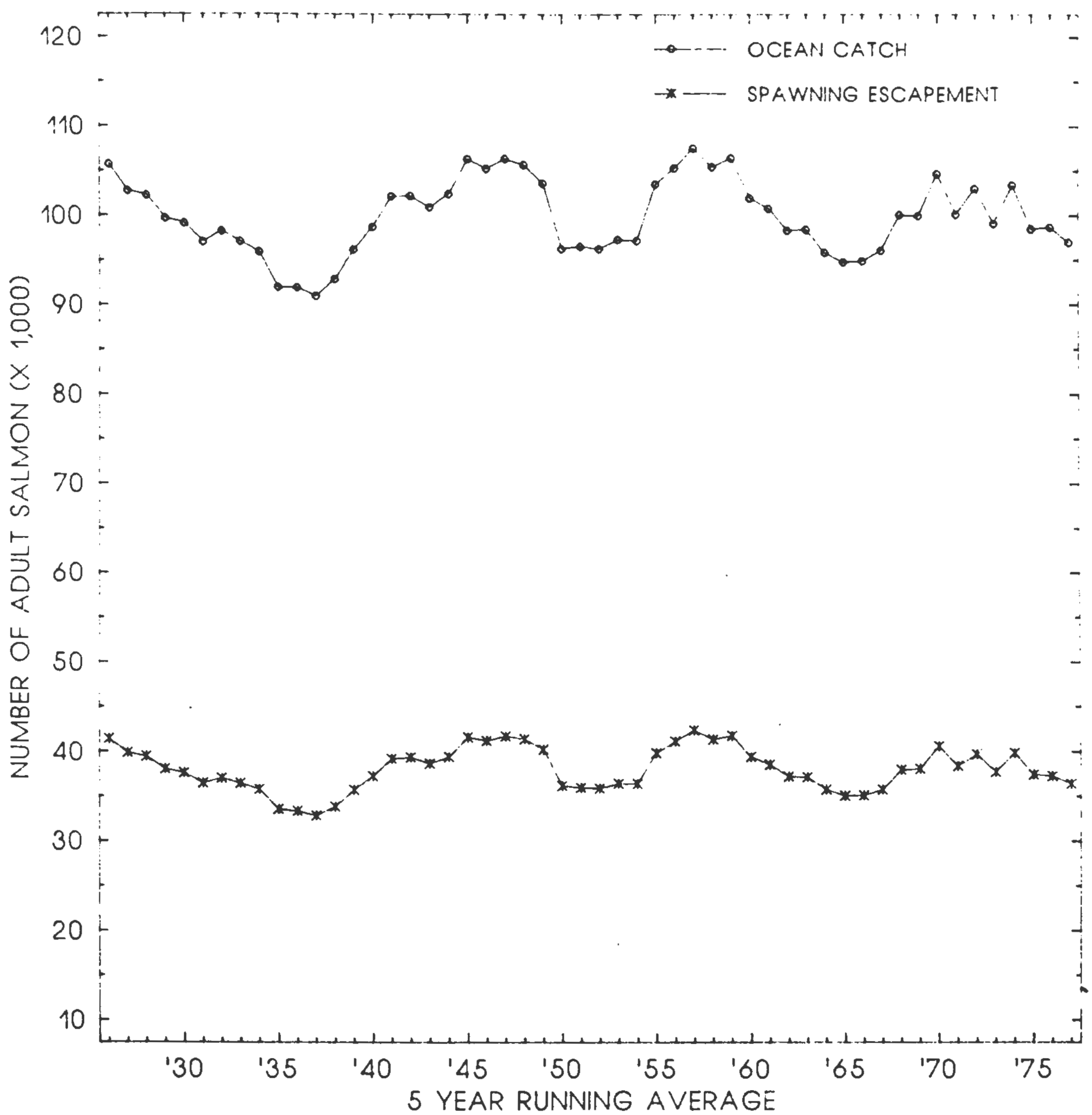

FIGURE 3-4. Mitchell predicted five-year running averages of estimated annual ocean catch and spawning escapement of adult (age 3, 4 and 5) fall run chinook salmon from the Feather River, based on estimated delta smolt mortality from years 1922-1978 of DWRSIM Operation Study 75D. Estimates represent combined natural and hatchery production from the Feather River. Spawning escapement includes adults that enter the Feather River Hatchery.

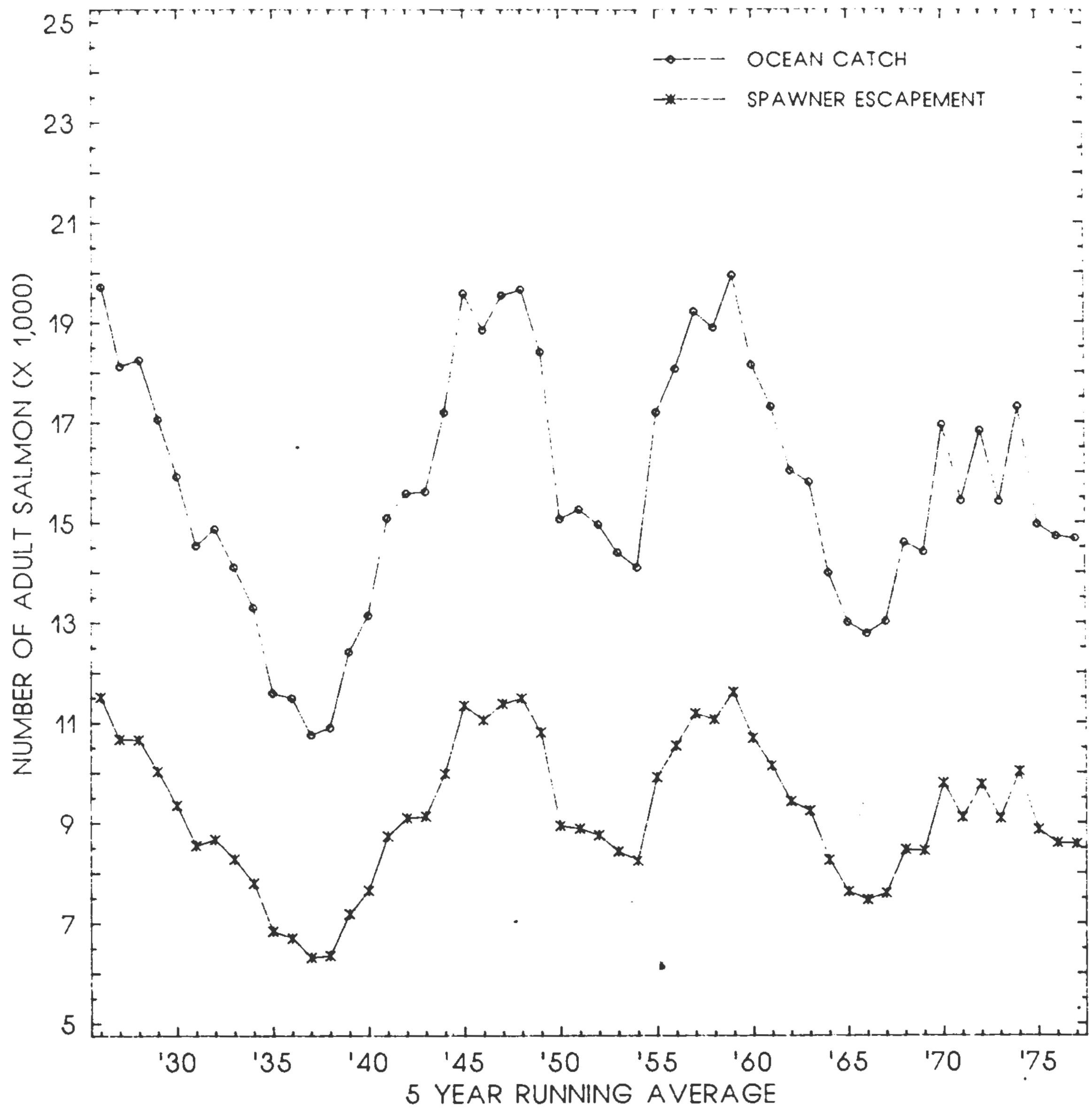

FIGURE 3-5. Mitchell predicted five-year running averages of estimated annual ocean catch and spawning escapement of adult (ages 3, 4 and 5) fall run chinook salmon from the Yuba River, based on estimated delta smolt mortality from years 1922-1978 of DWRSIM Operation Study 75D. Estimates represent natural production from the Yuba River.

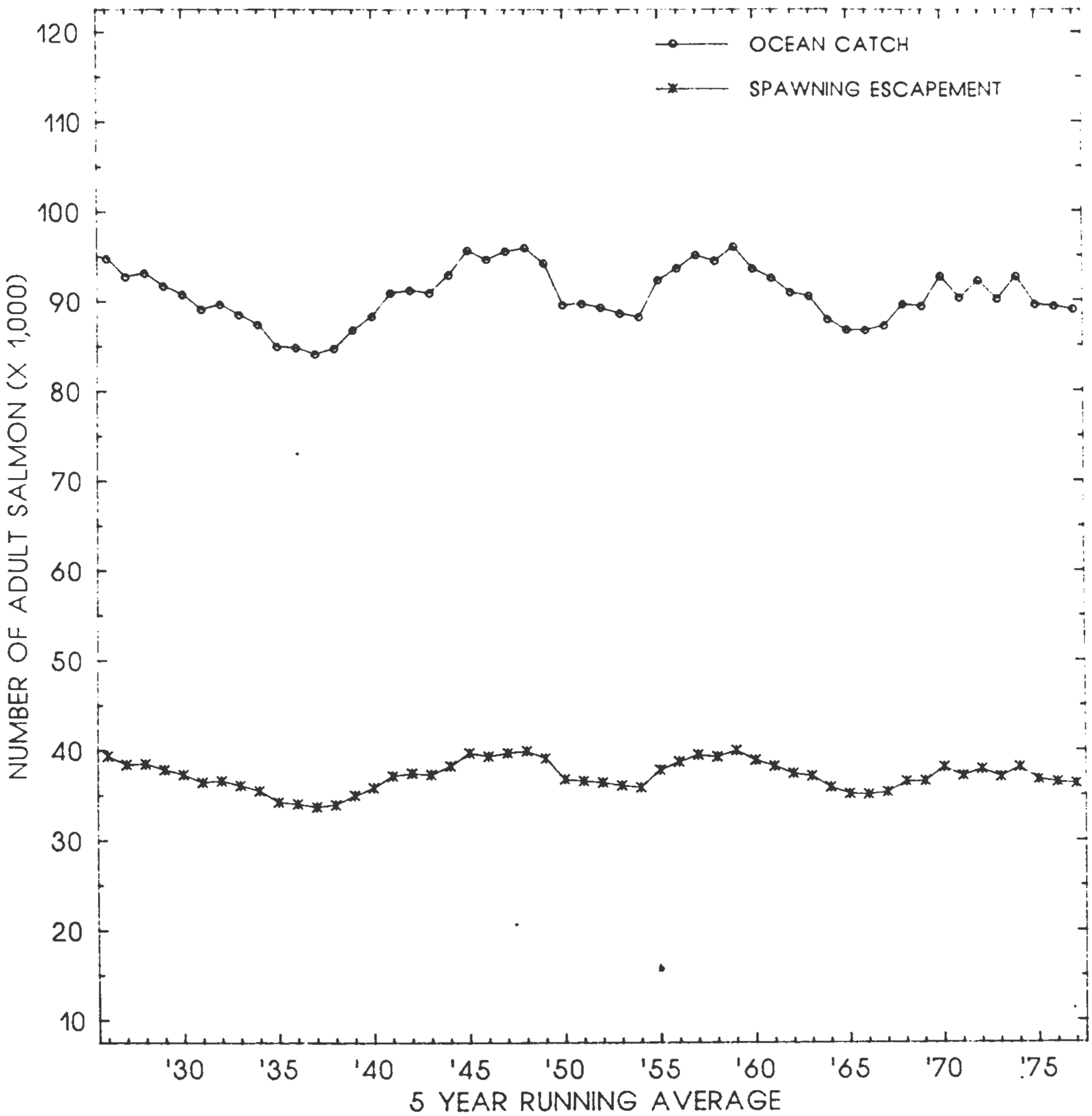

FIGURE 3-6. Mitchell predicted five-year running averages of estimated annual ocean catch and spawning escapement of adult (ages 3, 4 and 5) fall run chinook salmon from the American River, based on estimated delta smolt mortality from years 1922-1978 of DWRSIM Operation Study 75D. Estimates represent natural production from the American River. Spawning escapement includes adults that enter Nimbus Hatchery.

four major spawning areas: The upper Sacramento, the Yuba, the Feather, and the American rivers; and of the spawning escapements to each of those areas. Each 5-year running average was calculated from the model prediction of catch and escapement in that and the four preceding years. We initiated the 75D salmon model run for each of the four major natural chinook spawning areas by using the averages of the estimated number of adults spawning in those rivers from 1983-1987. The model converts those initial spawning escapement estimates to estimates of the number of smolts reaching the Delta. It does this using the four curves that Mitchell developed relating the numbers of spawners in each major area to the number of smolts produced in each area that reach the Delta at Sacramento.

A similar relationship was developed to represent the result of Coleman Hatchery production to Battle Creek escapement (Figure 2-5). Figure 3-7 illustrates the ocean catch and escapement to Battle Creek that can be attributed to the smolts reared at Coleman Hatchery. Because Coleman fish are planted in either Battle Creek or the Sacramento River above the Delta to avoid straying losses, annual estimates of smolts from Coleman were added to the estimate of naturally produced smolts from the Sacramento River Basin entering the Delta.

An average of 4 million smolts are currently planted in the estuary below the Delta from each of the Feather River and Nimbus hatcheries, annually, and to represent these in the Mitchell Model, 8 million smolts were added each year to the numbers of smolts leaving the Delta. Each year all of those smolts were subjected to an estimate of average bay and ocean mortality until they were caught in the ocean fishery or returned to the rivers to be caught in the sport fishery or to spawn. The development of ocean mortality, harvest, maturity, and straying rates was briefly described in Chapter II. Additional details are in Appendix A.

We believe that the 5-year running averages in Figures 3-3 through 3-7 and the long-term average Delta mortality, ocean catch, and spawning escapement estimated to result from Operation 75D (Table 3-5) are reasonable estimates of what would happen if the present system was operated in that way.

UPSTREAM CONDITIONS

All four races of chinook salmon have problems upstream--and those have been written about at length. In the upper Sacramento River they have been reasonably well defined; and, in the Feather, American, and Yuba rivers, the CDFG and others are working toward definitions. Eventually, salmon planning for the Central Valley should include resolving habitat and instream flow problems on all of these streams, but doing so is well beyond the scope of this report.

Those who wish to reduce Delta mortality, however, must be concerned about those upstream problems because changing lower Sacramento flows to improve Delta conditions for salmon can exacerbate them and damage habitat upstream. Our first attempt to increase spring flows for Delta smolts with an earlier Operation Study (62B) reduced the fall flows, lowered Shasta

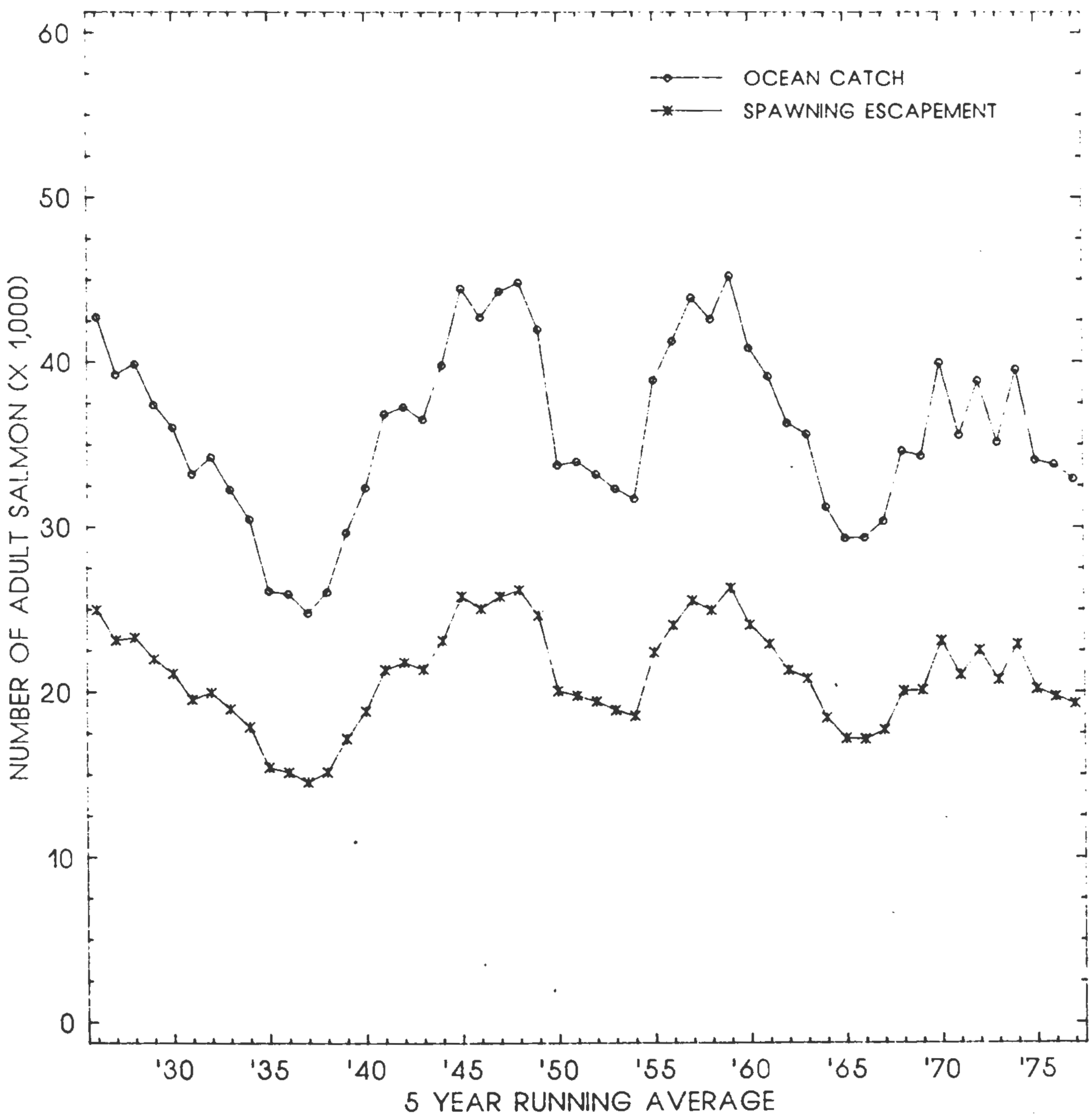

FIGURE 3-7. Mitchell predicted five-year running averages of estimated annual ocean catch and spawning escapement of adult (ages 3, 4 and 5) fall run chinook salmon from the Coleman Hatchery, based on estimated delta smolt mortality from years 1922-1978 of DWRSIM Operation Study 75D. Estimates represent hatchery production only. Spawning escapement is the number of adults returning to Battle Creek, including those that enter the hatchery.

TABLE 3-5. Summary of the effect of Baseline Operation Study 75D on fall run chinook salmon in the Sacramento River Basin.

1922 THROUGH 1977 AVERAGES	DELTA SURVIVAL	OCEAN CATCH	SPAWNING ESCAPEMENT
UPPER SACRAMENTO RIVER	0.25	93,379	54,584
FEATHER RIVER *	0.25	99,827	37,946
YUBA RIVER	0.25	15,724	9,191
AMERICAN RIVER *	0.25	90,589	37,091
COLEMAN HATCHERY	0.25	35,877	20,971
TOTAL BASIN	0.25	335,396	159,783

* Feather and American Rivers ocean catch and spawning escapement are both a combination of hatchery and natural river production. Since the hatchery portion (about half) is planted downstream of the delta, only the natural river portion is subject to the Delta Mortality.

** Coleman Hatchery adults returning to spawn are taken into the hatchery up to 7,700. There is inadequate information about the natural production, and it is not included in this model.

Reservoir, and raised temperatures in the upper Sacramento River to levels which would have been extremely damaging to both spawning activities and egg incubation. We have discussed these and other upstream problems at length with many fisheries professionals who work on them and decided that while these problems cannot be solved in this step of the 5-Agency Salmon Management Group process, we must make certain that they are not exacerbated by our attempts to solve Delta problems. For that, we need to provide a description of key upstream conditions provided for salmon by our baseline Operation 75D and compare it to those conditions provided by study 144C or any other study designed to improve conditions for salmon in the Delta.

For the upper Sacramento, we have made some preliminary assessments of how Operation Study 75D would affect spawning, egg stranding as flows decline after spawning, and the water temperatures which influence egg incubation and juvenile rearing and emigration. Since less is known (or at least agreed to) about the Yuba, Feather, and American rivers, we have listed only the end-of-month Oroville and Folsom reservoirs storage and the monthly flows in the Yuba, Feather, and American rivers -- and use them to assess the effect of modifying the base case operation. These are direct outputs of the DWRSIM model.

UPPER SACRAMENTO RIVER

Mean monthly flows in the Sacramento River at the mouth of Cottonwood Creek from DWRSIM Operation Study 75D are listed in Table 3-6. Preliminary information developed during the CDFG/CDWR Instream Flow Incremental Method studies being conducted there has been applied to these predicted flows and those at Keswick, Red Bluff and Thomes Creek. The IFIM work involves measuring depth, velocity, and substrate conditions along a large number of transects in the river from Keswick to Hamilton City and subsequently converting that data to indexes (termed "weighted usable area") of spawning habitat at different flows by using the USFWS's IFG and HABTAT models. At CDFG's request we used Bovee's (1978) "preference curves" to illustrate the process with the understanding that the calculations should be redone once site specific curves for the upper Sacramento are available.

Spawning

Tables 3-7 through 3-9 list the indices of weighted usable area for fall spawning that would occur in each of the 57 years if flows had been as they were in Operation 75D. We calculated these indices from the 75D estimates of monthly October, November, and December flow in these reaches, and the preliminary relationships between weighted usable area and flow from the IFIM data. We cannot calculate a spawning index for years when the mean monthly flows during October, November, or December exceed 15,000 cfs because that was the upper limit of the IFIM Program execution.

Egg Stranding

The stranding of eggs in salmon redds, when flows are dropped after spawning, is one of the more serious problems that biologists are concerned about on the upper Sacramento River The problem is particularly severe for the fall run, which spawns primarily in October, November, and December,

TABLE 3-6. Simulated mean monthly Sacramento River flow in the vicinity of Cottonwood Creek from DWRSIM Operation Study 75D.

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* CP NO  73   SACTO. RIVER AT COTTONWOOD CR.*   RIVER FLOW (REGULATED)---CFS
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YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1922	4556	4429	3253	2992	4393	3594	3680	9209	9461	15894	13824	6596
1923	4082	4997	4656	3350	4760	4439	3143	9292	11351	14528	12418	4715
1924	4270	5524	4745	3145	2485	5852	8047	7302	9028	11527	7699	5510
1925	3169	5819	2456	3547	7473	6901	4269	5302	14093	17532	11059	6513
1926	5842	5248	4671	2992	4952	3896	2907	8482	12011	15626	10907	6476
1927	4943	5042	4739	9026	34932	4147	12886	10105	9761	16117	15888	6577
1928	4378	6689	4883	3529	6362	19110	4517	8341	12586	16868	14909	6769
1929	6151	4666	3345	3211	2575	5905	9472	8098	8874	13925	9618	7544
1930	6626	6545	4755	3497	3655	3432	5382	7883	11774	14588	9582	5697
1931	6100	5363	6146	3143	3106	5905	8363	6895	10060	11930	8259	5427
1932	4161	4820	2944	3204	3115	2992	7255	7627	9913	10938	9009	6546
1933	4919	4050	2749	2309	2575	4122	6383	7710	8543	10641	7887	5492
1934	4203	5591	4352	2716	2809	2930	6055	6279	8061	11658	7522	5493
1935	4505	5126	4429	4050	4799	3074	4369	5607	12001	15590	10211	6395
1936	4268	4117	4524	4082	6158	3448	3348	7798	8940	15739	14894	6299
1937	5353	5823	4311	2765	3313	3562	3479	7520	11357	17152	10344	6710
1938	4249	5126	19930	6473	35292	40317	15394	10167	8731	11711	11098	10334
1939	10782	7682	4656	4363	3086	6426	11410	8488	11246	15999	10719	6915
1940	6611	7271	7902	4342	25566	24688	4470	6226	13041	16053	15963	6337
1941	5240	5268	12424	30283	29512	18199	21128	16301	11616	15754	14461	7289
1942	7592	8969	22822	23071	34248	3155	7914	15400	10986	15370	15536	6994
1943	6451	8439	8438	15093	9687	12702	6298	8534	12835	17655	15391	7228
1944	4467	5342	4928	2976	3547	2992	7597	8452	12269	16374	10994	6798
1945	5730	4369	3432	3672	4447	3220	4905	7196	10516	15316	14200	7088
1946	4519	6377	26705	9623	4481	2944	6614	9012	14028	16735	14945	6576
1947	5902	4708	3090	3172	3655	3627	5899	10307	12748	16597	11269	6695
1948	5303	4348	6312	6029	5018	7239	4235	3464	9434	14801	14916	5913
1949	6226	6384	4267	3407	4447	14060	6863	8072	12570	15202	10668	6228
1950	5594	5154	5712	3301	3979	3797	4432	9454	9753	12954	12239	6130
1951	5558	11163	18010	10216	18600	3106	7156	7261	11664	16029	15544	5789
1952	4438	4252	21011	11199	22338	13197	20850	13300	9514	11431	11034	10334
1953	10148	6995	14585	34975	3681	5047	7248	13169	12744	14923	13813	6240
1954	8719	11421	7078	16377	22396	11433	15388	11633	13276	16362	14613	6121
1955	5534	4554	8919	3529	4011	5640	9617	8289	11675	16634	11060	6106
1956	5981	6003	23885	35921	27057	4476	5099	16235	8993	14505	14368	5906
1957	9495	7348	4389	2960	14276	11018	8428	9666	9604	14088	15314	6302
1958	8188	10985	13978	15405	44578	48454	19249	11276	12493	14545	12803	7975
1959	10695	7454	5224	12924	16999	3271	10613	9755	12471	18396	12386	5716
1960	6557	6975	6720	4366	5744	5253	8918	7934	13976	18058	11334	6447
1961	6197	5067	5937	4115	5168	4745	9706	10127	12425	18855	12186	6659
1962	6838	6752	4305	4866	10923	3773	7249	8138	12002	16620	13339	6188
1963	4456	8302	9996	3220	14798	7189	33060	9505	10542	15117	15616	6154
1964	5270	10181	5558	5735	3544	5862	11282	9618	11610	14410	10910	6012
1965	5688	4594	18986	24754	3799	4088	14309	8125	10110	15174	14118	6100
1966	4645	10944	6444	8330	7707	13316	8971	9188	12284	17264	13871	5977
1967	6845	5946	16861	12601	9696	16006	12686	18672	12708	11320	11392	11053
1968	10708	7517	5907	4115	25732	3666	7753	8291	11878	17125	11210	6707
1969	6332	4309	4082	28474	26530	8491	14819	15958	9928	11020	11078	11507
1970	10845	7499	19937	60107	18934	4180	9633	8072	11695	16769	12992	6234
1971	4492	7438	20924	18076	6083	21052	5449	14916	10833	14596	14180	5669
1972	9922	8013	5915	4354	6519	12376	12798	9372	12866	15420	14594	5689
1973	4944	4857	8519	18857	24145	9574	4448	11436	15407	16207	11372	6005
1974	4482	31762	25892	46566	10458	42864	12840	10671	10613	12116	14343	8729
1975	10702	8136	5800	3106	13154	32409	4067	17033	11412	14293	12243	7235
1976	11746	8434	5379	4784	6942	5824	9113	8838	10422	15778	10794	6085
1977	7274	6716	7725	6049	5466	5329	6971	5592	7924	10926	7706	3617
1978	4276	6977	7967	9053	15710	20135	8236	10320	11715	13796	11072	5095
AVG.	6266	6910	8904	10323	11569	9797	8889	9595	11235	14957	12311	6613

TABLE 3-7. October weighted useable area indexes for chinook salmon spawning in the upper Sacramento river, calculated using USFWS, IFG and HABITAT models using flows from our baseline DWRSIM Operation Study 75D.

YEAR	ACID-DAM COTTONWOOD	COTTONWOOD RED BLUFF	RED BLUFF TEHEMA	TEHEMA HAMILTON CITY	TOTAL
1921	7601504.	3918527.	9532964.	3465770.	24518764.
1922	11439000.	4054280.	9532964.	3465770.	28492014.
1923	11439000.	3918527.	9532964.	3465770.	28356260.
1924	13809000.	4925939.	9908091.	3036961.	31679992.
1925	6174696.	2692389.	7741681.	2424716.	19033482.
1926	5885890.	4105631.	7919523.	2833246.	20744290.
1927	11439000.	3918527.	9532964.	3465770.	28356260.
1928	6236891.	2692389.	7579362.	2009993.	18518636.
1929	5883978.	1610581.	6240027.	1876015.	15610601.
1930	6236891.	2692389.	7579362.	2009993.	18518636.
1931	11439000.	4054280.	10129000.	3525155.	29147436.
1932	5885890.	4105631.	9532964.	3465770.	22990256.
1933	11439000.	4054280.	10129000.	3525155.	29147436.
1934	7601504.	3918527.	9532964.	3465770.	24518764.
1935	11439000.	3918527.	10129000.	3525155.	29011682.
1936	5885890.	3922376.	7919523.	2833246.	20561036.
1937	11439000.	4054280.	9532964.	3465770.	28492014.
1938	4903473.	634297.	4621318.	2466217.	12625305.
1939	5883978.	1610581.	6240027.	1876015.	15610601.
1940	5885890.	4105631.	7919523.	2833246.	20744290.
1941	5811977.	1007243.	7043094.	2910654.	16772968.
1942	5883978.	1610581.	7579362.	2009993.	17083914.
1943	7601504.	3918527.	9532964.	3465770.	24518764.
1944	6174696.	3922376.	7741681.	2424716.	20263468.
1945	7601504.	3918527.	9532964.	3465770.	24518764.
1946	6174696.	2692389.	7741681.	2424716.	19033482.
1947	5885890.	3922376.	7741681.	2009993.	19559940.
1948	6236891.	2692389.	7579362.	2009993.	18518636.
1949	6174696.	3922376.	7919523.	2833246.	20849840.
1950	5885890.	3922376.	7579362.	1876015.	19263644.
1951	11439000.	3918527.	9532964.	3465770.	28356260.
1952	4751044.	762822.	5476606.	2862876.	13853348.
1953	5804827.	564824.	7452438.	4412247.	18234336.
1954	6174696.	3922376.	7741681.	2424716.	20263468.
1955	6236891.	2692389.	7741681.	2424716.	19095676.
1956	5305152.	597493.	5711781.	3162718.	14777144.
1957	5811977.	680634.	5711781.	3162718.	15367110.
1958	4903473.	661774.	4621318.	2466217.	12652782.
1959	5883978.	1610581.	6240027.	1876015.	15610601.
1960	6236891.	2692389.	7579362.	2009993.	18518636.
1961	5883978.	1262957.	6240027.	1876015.	15262977.
1962	11439000.	3918527.	5956466.	1876905.	23190898.
1963	5885890.	3922376.	7579362.	2009993.	19397620.
1964	6174696.	3922376.	7741681.	2424716.	20263468.
1965	7601504.	3918527.	9532964.	3465770.	24518764.
1966	5883978.	1262957.	6240027.	1876015.	15262977.
1967	4903473.	661774.	5476606.	2862876.	13904729.
1968	6236891.	1610581.	6240027.	1876015.	15963514.
1969	4903473.	634297.	4621318.	2466217.	12625305.
1970	7601504.	3918527.	9532964.	3465770.	24518764.
1971	4623009.	762822.	5476606.	2862876	13725313.
1972	7601504.	4105631.	7741681.	2424716.	21873532.
1973	11439000.	3918527.	7919523.	2833246.	26110296.
1974	4903473.	661774.	4994236.	2582423.	13141906.
1975	3312357.	779747.	4324796.	1696433.	10113333.
1976	6166606.	1007243.	5956466.	1876905.	15007220.
1977	11439000.	3918527.	10129000.	3525155.	29011682.
AVG.	7191710.	2784697.	7619145.	2714674.	20310226.

TABLE 3-8. November weighted useable area indexes for chinook salmon spawning in the upper Sacramento River, calculated using USFWS, IFG and HABITAT models using flows from our baseline DWRSIM Operation Study 75D. Flows greater than 15,000 cfs can not be evaluated and are indicated by nulls.

YEAR	ACID-DAM COTTONWOOD	COTTONWOOD RED BLUFF	RED BLUFF TEHEMA	TEHEMA HAMILTON CITY	TOTAL
1921	11439000.	3918527.	9532964.	3465770.	28356260.
1922	7601504.	4105631.	7741681.	2009993.	21458808.
1923	6174696.	3922376.	7741681.	2424716.	20263468.
1924	6174696.	2692389.	6240027.	1876905.	16984016.
1925	5885890.	4105631.	7919523.	2833246.	20744290.
1926	11439000.	4105631.	6240027.	1876905.	23661564.
1927	6236891.	1610581.	7452438.	3395724.	18695634.
1928	11439000.	3918527.	7741681.	2424716.	25523924.
1929	5883978.	1610581.	6240027.	1876015.	15610601.
1930	5885890.	3922376.	7741681.	2424716.	19974664.
1931	7601504.	4105631.	7919523.	2833246.	22459904.
1932	11439000.	4054280.	10129000.	3525155.	29147436.
1933	6174696.	3922376.	7741681.	2424716.	20263468.
1934	7601504.	4105631.	5956466.	1876905.	19540506.
1935	11439000.	4054280.	10129000.	3525155.	29147436.
1936	6174696.	2692389.	7741681.	2424716.	19033482.
1937	11439000.	4105631.	4994236.	2212335.	22751202.
1938	5811977.	1007243.	7119500.	3742028.	17680748.
1939	6166606.	1007243.	5956466.	1876905.	15007220.
1940	5885890.	3922376.	7741681.	2009993.	19559940.
1941	5804827.	550937.	5711781.	3162718.	15230263.
1942	6110750.	564824.	7452438.	3395724.	17523736.
1943	5885890.	3922376.	7741681.	2424716.	19974664.
1944	11439000.	3918527.	7579362.	2009993.	24946882.
1945	6236891.	1610581.	7043094.	3742028.	18632594.
1946	7601504.	3918527.	7919523.	2833246.	22272800.
1947	11439000.	3918527.	9532964.	2833246.	27723736.
1948	6236891.	1610581.	6240027.	1876015.	15963514.
1949	5885890.	4105631.	7919523.	2833246.	20744290.
1950	4903473.	634297.	4324796.	1917411.	11779977.
1951	11439000.	3918527.	7741681.	2424716.	25523924.
1952	5883978.	1262957.	7043094.	2910654.	17100684.
1953	3941901.	779747.	4782845.	1838988.	11343481.
1954	11439000.	3918527.	7579362.	1876015.	24812904.
1955	6174696.	2692389.	5956466.	2910654.	17734204.
1956	6166606.	1007243.	7043094.	3742028.	17958972.
1957	4903473.	634297.	4782845.	1696433.	12017048.
1958	6166606.	1007243.	7119500.	3742028.	18035376.
1959	6166606.	1262957.	5956466.	1876905.	15262934.
1960	5885890.	4105631.	7579362.	2009993.	19580876.
1961	5883978.	1262957.	7043094.	2910654.	17100684.
1962	6110750.	564824.	6329859.	3395724.	16401157.
1963	4623009.	762822.	4324796.	1696433.	11407060.
1964	11439000.	3918527.	6240027.	1876015.	23473568.
1965	4751044.	634297.	4324796.	1917411.	11627548.
1966	6174696.	2692389.	5956466.	2910654.	17734204.
1967	6166606.	1007243.	7043094.	2910654.	17127596.
1968	11439000.	3918527.	7919523.	2833246.	26110296.
1969	6166606.	1007243.	7119500.	3742028.	18035376.
1970	5883978.	1007243.	4782845.	1696433.	13370499.
1971	5811977.	680634.	7452438.	4412247.	18357296.
1972	11439000.	4105631.	5956466.	1876905.	23378002.
1973	****	****	****	****	****
1974	6110750.	680634.	6329859.	3395724.	16516967.
1975	6110750.	564824.	6329859.	3395724.	16401157.
1976	5883978.	1610581.	6240027.	1876015.	15610601.
1977	5883978.	1262957.	7043094.	2910654.	17100684.
AVE.	7276526.	2462768.	61919761 .	2622735.	19422738.

TABLE 3-9. December weighted useable area indexes for chinook salmon spawning in the upper Sacramento River, calculated using USFWS, IFG and HABITAT models and flows from our baseline DWRSIM Operation Study 75D. Flows greater than 15,000 cfs can not be evaluated and are indicated by nulls.

YEAR	ACID-DAM COTTONWOOD	COTTONWOOD RED BLUFF	RED BLUFF TEHEMA	TEHEMA HAMILTON CITY	TOTAL
1921	0.	5376114.	7741681.	2009993.	15127788.
1922	11439000.	3918527.	7452438.	3395724.	26205688.
1923	7601504.	3918527.	7919523.	2833246.	22272800.
1924	0.	0.	10129000.	3525155.	13654155.
1925	7601504.	3918527.	7741681.	2424716.	21686428.
1926	15559000.	3918527.	5476606.	2466217.	27420350.
1927	11439000.	4105631.	5956466.	1876905.	23378002.
1928	13809000.	5376114.	9532964.	3465770.	32183848.
1929	15559000.	4105631.	5956466.	2910654.	28531752.
1930	6236891.	2692389.	7579362.	2009993.	18518636.
1931	0.	4925939.	7119500.	3742028.	15787467.
1932	0.	0.	9941166.	3437072.	13378238.
1933	11439000.	3918527.	6240027.	1876015.	23473568.
1934	11439000.	3918527.	7919523.	2424716.	25701766.
1935	7601504.	3918527.	7919523.	2833246.	22272800.
1936	11439000.	3918527.	9532964.	3465770.	28356260.
1937	****	****	****	****	****
1938	11439000.	3918527.	7741681.	2009993.	25109200.
1939	5811977.	680634.	7452438.	3395724.	17340772.
1940	5804827.	413873.	****	****	****
1941	****	****	****	****	****
1942	5811977.	564824.	5476606.	2582423.	14435830.
1943	7601504.	4105631.	7919523.	2833246.	22459904.
1944	0.	5376114.	7741681.	2009993.	15127788.
1945	****	****	****	****	****
1946	0.	4925939.	10129000.	3525155.	18580094.
1947	6236891.	1610581.	6240027.	1876015.	15963514.
1948	11439000.	3918527.	7919523.	2833246.	26110296.
1949	6174696.	3922376.	7579362.	2009993.	19686428.
1950	****	****	****	****	****
1951	****	****	****	****	****
1952	3312357.	501055.	****	****	****
1953	5883978.	1262957.	7043094.	2910654.	17100684.
1954	6110750.	550937.	4461252.	1838988.	12961927.
1955	****	****	****	****	****
1956	11439000.	3918527.	9532964.	3465770.	28356260.
1957	3135147.	339220.	****	****	****
1958	5885890.	4105631.	7741681.	2424716.	20157918.
1959	5883978.	1610581.	5956466.	1876905.	15327930.
1960	5885890.	2692389.	5711781.	3162718.	17452778.
1961	15559000.	3918527.	7119500.	3742028.	30339056.
1962	5305152.	762822.	4479531.	1889638.	12437143.
1963	5885890.	3922376.	7579362.	1876015.	19263644.
1964	3556700.	****	****	****	****
1965	6236891.	1610581.	7043094.	2910654.	17801220.
1966	****	****	****	****	****
1967	6174696.	2692389.	5956466.	1876905.	16700456.
1968	0.	4054280.	5711781.	3162718.	12928779.
1969	****	****	****	****	****
1970	****	****	****	****	****
1971	6174696.	2692389.	7043094.	2910654.	18820832.
1972	6166606.	564824.	4461252.	1838988.	13031670.
1973	****	****	****	****	****
1974	6174696.	2692389.	7043094.	2910654.	18820832.
1975	5885890.	3922376.	7579362.	1876015.	19263644.
1976	5811977.	1007243.	7043094.	2910654.	16772968.
1977	5883978.	680634.	4621318.	2212335.	13398265.
AVG.	6762478.	2844982.	7174115.	2641163.	19422738.

depositing eggs that incubate for about 2 months after they are placed in the gravel. We developed a stranding index as a rough assessment of the magnitude of this problem.

The IFG4 model takes measurements of depth, mean column velocity, and substrate classifications made on numerous transects across the river and converts them to predictions of the average level of these variables in a large number of rectangular "cells" at a range of flows. Our approach to developing an index of egg stranding was to estimate to what degree cells that were suitable for spawning at a given flow in one month would be left without sufficient depth or current velocities for egg incubation within the following two months.

Nineteen transects were selected as having the largest amount of substrate suitable for spawning. We selected those with at least 10 cells dominated by any mix of substrate materials ranging from 0.25 to 6 inches in diameter but with no more than 70% of the substrate in either the 0.25 - 2" category or the 2 - 6 " category. 595 cells in 19 transects met these criteria.

Using IFG4 program output, we obtained a depth and mean column velocity in each of these cells at 500 cfs flow increments between 15,000 to 3,000 cfs. The relationships between depth and river flow, and between mean column velocity and river flow were thus defined for each cell. Those relationships were then applied to the mean monthly flows predicted by the 75D Operation Study to determine whether that cell provided spawning habitat at the predicted flow and if within the following two months, conditions in that same cell provided a risk of significant egg mortality because flows had declined.

A cell was considered spawning habitat if the predicted water depth was between 0.5 and 10 feet, and the mean column velocity was between 1.5 and 2.5 feet per second. If the mean water depth in such a cell fell below 0.5 feet, it was judged subject to significant risk of egg mortality caused by the declining flows. This criteria probably exaggerates the risk, but we wanted a conservative assessment.

The percentage of spawning cells that were subjected to water depths less than 0.5 feet during the two months after spawning could have occurred provides an index of egg stranding for each transect and each year. For these calculations we assumed that spawning occurred in October, November and December since the October through January period appear to be those with the greatest risk of stranding the eggs of fall run salmon.

Over the 57 years of flows predicted by Operation 75D, 16% of the cells we have judged suitable for spawning on these transects would been subjected to a risk of stranding (Table 3-10). These indexes ranged from 0 to 39%. Most of the risk occurred to redds built in the river upstream of the Red Bluff Diversion Dam.

These indexes are not intended as absolute estimates of egg stranding, but we believe they can be used to compare the effect of different operation studies on this problem.

TABLE 3-10. Indexes of chinook salmon egg stranding in the upper Sacramento River, calculated using flows from baseline DWRSIM Operation Study 75D.

NUMBER OF IFIM CELLS SUITABLE FOR SPAWNING AND INCUBATION

YEAR	ACID DAM TO RED BLUFF NUMBER SPAWNING	ACID DAM TO RED BLUFF NUMBER INCUBATING	RED BLUFF TO HAMILTON CITY NUMBER SPAWNING	RED BLUFF TO HAMILTON CITY NUMBER INCUBATING	NUMBER SUBSEQUENTLY REDUCED TO <0.5' DEEP	PERCENT SUBSEQUENTLY REDUCED TO <0.5' DEEP
1921	82	82	65	26	39	27
1922	77	71	80	41	45	29
1923	79	78	83	52	32	20
1924	92	90	54	6	50	34
1925	75	75	89	46	43	26
1926	66	66	79	78	1	1
1927	73	69	83	44	43	28
1928	77	76	75	54	22	14
1929	65	65	83	50	33	22
1930	71	70	91	66	26	16
1931	84	78	63	25	44	30
1932	105	103	57	5	54	33
1933	80	80	78	23	55	35
1934	74	74	85	50	35	22
1935	93	93	79	44	35	20
1936	79	78	86	46	41	25
1937	49	49	49	49	0	0
1938	68	55	63	43	33	25
1939	65	65	82	52	30	20
1940	49	49	72	72	0	0
1941	50	50	43	43	0	0
1942	68	68	73	73	0	0
1943	79	78	86	43	44	27
1944	72	71	66	27	40	29
1945	54	54	61	61	0	0
1946	84	81	71	28	46	30
1947	71	71	89	89	0	0
1948	69	67	91	87	6	4
1949	73	73	85	42	43	27
1950	39	39	40	39	1	1
1951	54	54	54	54	0	0
1952	50	48	53	43	12	12
1953	70	67	60	58	5	4
1954	66	55	74	44	41	29
1955	48	48	62	62	0	0
1956	78	61	69	31	55	37
1957	43	43	44	44	0	0
1958	69	57	69	67	14	10
1959	61	61	88	71	17	11
1960	70	61	92	70	31	19
1961	72	71	82	82	1	1
1962	58	38	63	40	43	36
1963	63	57	72	68	10	7
1964	46	46	60	56	4	4
1965	73	70	72	71	4	3
1966	44	44	60	60	0	0
1967	70	67	71	33	41	29
1968	70	69	70	34	37	26
1969	44	44	39	38	1	1
1970	48	48	58	58	0	0
1971	75	66	69	69	9	6
1972	65	65	80	80	0	0
1973	25	25	26	26	0	0
1974	68	52	64	28	52	39
1975	61	50	61	58	14	11
1976	67	64	84	84	3	2
1977	79	79	82	82	0	0
AVG.	67	64	70	51	22	28

Egg Mortality from High Water Temperature

The high water temperatures which cause egg and juvenile mortality in the upper Sacramento have been defined as a major problem for upper Sacramento River salmon stocks. Jack Rowell, of the USBR, has calculated mean monthly temperatures in various parts of the Sacramento River from Keswick to Freeport using the 75D simulation and his temperature models. He can do that with any operation study and the details may be compared with his 75D output. A rapid comparison can be done by comparing the frequency that temperatures exceed what biologists agree are undesirable levels.

There is general agreement among biologists that if temperatures exceed 56°F for more than a few days a large portion of the salmon eggs in the gravel will be killed.

Salmon from one of the four runs are spawning in the Sacramento River somewhere between Hamilton City and Keswick in every month of the year. Our examination of the USGS daily temperature data from the Upper Sacramento River indicated that if mean monthly temperatures exceeded 56°F, the fish would have probably experienced several days of consecutive mean daily temperatures exceeding the safe 56°F. Table 3-11 describes the percent of the Octobers, Novembers, etc., when the mean monthly water temperatures would exceed 56°F in the various reaches of the river. These frequencies indicate when, where and how often water temperatures would likely be too warm for salmon eggs.

USBR's temperature model run from which Table 3-11 is derived, assumes that an effective device to provide temperature control has been installed in Shasta Reservoir. Although that device will much improve conditions, Table 3-11 is evidence that with Operation 75D warm water would continue to be a problem for the eggs of some winter run fish that spawn in the spring and of more of the fall run fish that spawn in October.

Effect of High Water Temperature on Juvenile Rearing and Emigration.

Table 3-12 lists the percent of the month during which water temperatures exceed 64°, 69°, and 74°F between Keswick and Freeport. We list three temperatures because the indirect effects of temperatures within this range are much more subtle and complex and are less understood than the direct effect of temperature on eggs. Among other things, they depend on the duration of exposure, the amount and availability of food, and the population of predators.

Juvenile salmon are emigrating down the Sacramento River at all months of the year, and, although there is general agreement on the emigration times of the most abundant fall run, there is considerable disagreement about the emigration times of the other runs. With 75D any emigrants attempting to move through the Wilkens Slough to Freeport reach risk higher than desirable temperatures from June through September.

SHASTA, OROVILLE, AND FOLSOM RESERVOIRS

Tables 3-13 through 3-15 list the end-of-the-month storage at Shasta, Oroville, and Folsom reservoirs if operated under the conditions of Study 75D. We present the levels here as a baseline against which anyone can compare the

TABLE 3-11. Percentages of months of the 57 year period when the Sacramento River at several locations between Keswick and Butte City exceeds mean monthly water temperatures of 56° -- and major egg mortality of salmon eggs would be expected with baseline Study 75D. Temperatures were calculated with USBR Temperature Model by Jack Rowell.

Percentages of months exceeding 56°F

STATION	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
KESWICK	18.	11.	0.	0.	0.	5.	0.	0.	0.	0.	9.	11.
COTTONWD	20.	9.	0.	0.	0.	5.	14.	7.	9.	7.	11.	23.
BEND BR	21.	5.	0.	0.	0.	4.	16.	21.	41.	20.	23.	48.
RED BLUFF	27.	4.	0.	0.	0.	4.	27.	48.	80.	38.	50.	70.
GCID	46.	0.	0.	0.	0.	4.	57.	95.	100.	100.	100.	100.
BUTTE CITY	70.	0.	0.	0.	0.	4.	71.	100.	100.	100.	100.	100.

TABLE 3-12. Percentages of months of the 57 year period when the average monthly Sacramento River temperature at several locations between Keswick and Freeport exceeds 64°F, 69°F and 74°F.

Percentages of months exceeding 64°F

STATION	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
KESWICK	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	7.
COTTONWD	2.	0.	0.	0.	0.	0.	0.	0.	0.	0.	4.	9.
BEND BR	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	5.	9.
RED BLUFF	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	9.	9.
GCID	2.	0.	0.	0.	0.	0.	0.	0.	7.	9.	11.	9.
BUTTE CITY	2.	0.	0.	0.	0.	0.	0.	18.	88.	79.	68.	63.
WILKENS SL	2.	0.	0.	0.	0.	0.	0.	52.	100.	100.	98.	84.
COLUSA B D	2.	0.	0.	0.	0.	0.	2.	66.	100.	100.	100.	96.
FEATHER RV	2.	0.	0.	0.	0.	0.	2.	73.	100.	100.	100.	98.
AMERICN RV	2.	0.	0.	0.	0.	0.	2.	54.	100.	100.	100.	100.
FREEPORT	2.	0.	0.	0.	0.	0.	2.	55.	100.	100.	100.	100.

Percentage of months exceeding 69°F

STATION	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
KESWICK	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
COTTONWD	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
BEND BR	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
RED BLUFF	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
GCID	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	4.	2.
BUTTE CITY	0.	0.	0.	0.	0.	0.	0.	0.	4.	9.	11.	4.
WILKENS SL	0.	0.	0.	0.	0.	0.	0.	2.	43.	29.	41.	14.
COLUSA B D	0.	0.	0.	0.	0.	0.	0.	5.	71.	68.	61.	20.
FEATHER RV	0.	0.	0.	0.	0.	0.	0.	7.	84.	98.	91.	48.
AMERICN RV	0.	0.	0.	0.	0.	0.	0.	4.	57.	96.	91.	52.
FREEPORT	0.	0.	0.	0.	0.	0.	0.	5.	61.	100.	96.	52.

Percentage of months exceeding 74°F

STATION	OCT	NOV	DEC	JAN	FEB	MAY	APR	MAY	JUN	JUL	AUG	SEP
KESWICK	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
COTTONWD	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
BEND BR	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
RED BLUFF	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
GCID	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
BUTTE CITY	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
WILKENS SL	0.	0.	0.	0.	0.	0.	0.	0.	0.	4.	9.	0.
COLUSA B D	0.	0.	0.	0.	0.	0.	0.	0.	0.	4.	11.	0.
FEATHER RV	0.	0.	0.	0.	0.	0.	0.	0.	2.	11.	14.	0.
AMERICN RV	0.	0.	0.	0.	0.	0.	0.	0.	0.	4.	9.	0.
FREEPORT	0.	0.	0.	0.	0.	0.	0.	0.	0.	5.	9.	0.

TABLE 3-13. End of month storage in Shasta Reservoir from DWRSIM Operation Study 75D.

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* CP NO    4    SHASTA LAKE                 *     END OF PERIOD STORAGE---TAF
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YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1922	2559	2582	2809	2961	3378	3828	4430	4552	4371	3784	3282	3184
1923	3258	3252	3369	3619	3722	3796	4256	4102	3739	3199	2764	2775
1924	2824	2735	2694	2748	2983	2877	2643	2412	2084	1707	1555	1488
1925	1595	1664	1870	2009	3305	3486	4273	4466	3959	3227	2862	2764
1926	2720	2692	2697	2792	3561	3751	4194	3991	3500	2862	2499	2374
1927	2357	2820	3347	3668	3462	4142	4552	4552	4372	3779	3178	3084
1928	3111	3252	3363	3695	4099	3965	4552	4501	4069	3419	2862	2742
1929	2653	2662	2753	2860	3133	3197	3084	2948	2694	2188	1930	1756
1930	1642	1505	2020	2267	2683	3224	3389	3274	2826	2273	2014	1949
1931	1860	1791	1676	1806	1944	1999	1821	1671	1350	962	787	744
1932	719	649	941	1133	1306	1799	1845	1878	1605	1288	1065	873
1933	756	711	742	849	958	1576	1749	1751	1594	1296	1134	1040
1934	988	858	950	1318	1715	2016	2026	1939	1710	1330	1175	1031
1935	945	1023	1052	1399	1714	2158	3198	3506	3112	2514	2209	2091
1936	2023	1969	1923	2568	3500	3909	4264	4170	3975	3358	2757	2633
1937	2560	2414	2341	2363	2492	3189	3958	4140	3850	3155	2825	2686
1938	2704	3246	3310	3668	3560	3416	4058	4552	4552	4270	3973	3700
1939	3400	3252	3370	3477	3639	3901	3620	3399	2968	2333	2012	1879
1940	1774	1611	1573	2473	3252	3435	4312	4418	3990	3393	2762	2674
1941	2670	2645	3293	3317	3423	3940	4456	4552	4552	4061	3594	3524
1942	3400	3252	3316	3389	3516	3972	4552	4552	4552	4059	3518	3460
1943	3400	3252	3356	3541	3848	4118	4552	4552	4206	3551	3008	2909
1944	2951	2922	2904	3033	3391	3756	3746	3652	3296	2672	2346	2225
1945	2187	2355	2720	2931	3745	4110	4340	4448	4214	3643	3119	2992
1946	3088	3252	3265	3622	3849	4284	4530	4479	4000	3383	2854	2755
1947	2692	2742	2912	2969	3274	3848	3990	3702	3409	2769	2421	2304
1948	2362	2377	2268	2719	2740	2865	3871	4552	4552	4046	3485	3442
1949	3362	3252	3301	3333	3505	4071	4368	4381	3945	3373	3041	2946
1950	2880	2808	2696	3028	3475	3945	4352	4216	3913	3450	3025	2939
1951	3249	3252	3322	3624	3794	4318	4441	4552	4179	3567	2980	2928
1952	2984	3167	3306	3604	3739	4022	4290	4552	4552	4283	3975	3700
1953	3400	3252	3345	3366	3856	4279	4552	4552	4552	4080	3625	3601
1954	3400	3252	3364	3552	3661	4106	4546	4552	4169	3588	3113	3105
1955	3099	3239	3360	3563	3718	3772	3838	3925	3578	2929	2586	2527
1956	2454	2438	3252	3252	3288	4014	4552	4552	4552	4087	3609	3602
1957	3400	3252	3303	3471	3675	4129	4334	4552	4361	3905	3356	3361
1958	3400	3252	3338	3531	4552	3416	4173	4552	4552	4153	3794	3691
1959	3400	3252	3333	3648	3777	4261	4223	4070	3675	2956	2573	2596
1960	2517	2360	2230	2393	3155	3816	3848	3899	3486	2786	2443	2359
1961	2299	2358	2732	2950	3715	4231	4240	4174	3825	3065	2665	2564
1962	2456	2427	2766	2830	3675	4249	4476	4445	4075	3430	2960	2881
1963	3392	3252	3349	3593	3944	4226	4137	4552	4334	3839	3292	3274
1964	3296	3252	3366	3705	3923	3948	3712	3491	3189	2651	2314	2238
1965	2189	2300	3252	3368	3900	4137	4500	4552	4290	3768	3291	3254
1966	3283	3252	3359	3725	4037	4229	4496	4552	4152	3490	3009	2978
1967	2863	3135	3335	3551	3920	4033	4479	4552	4552	4300	4000	3700
1968	3400	3252	3370	3659	3654	4248	4299	4232	3867	3220	2937	2870
1969	2824	2885	3305	3358	3480	4030	4434	4552	4552	4300	4000	3700
1970	3400	3252	3317	3252	3431	4161	4162	4185	3881	3273	2884	2848
1971	2930	3252	3319	3515	3966	3873	4498	4552	4552	4107	3626	3634
1972	3400	3252	3365	3714	3979	4249	4295	4259	3863	3318	2829	2834
1973	2918	3173	3346	3552	3636	4162	4552	4552	4010	3425	3099	3081
1974	3220	3252	3267	3252	3694	3416	4289	4552	4552	4283	3829	3692
1975	3400	3252	3380	3584	3940	3800	4544	4552	4552	4110	3757	3691
1976	3400	3252	3380	3398	3434	3559	3489	3315	2997	2395	2136	2096
1977	1993	1878	1707	1632	1603	1579	1448	1402	1218	916	818	937
1978	1019	968	1289	3198	3650	3960	4552	4552	4227	3782	3464	3515
AVG.	2674	2665	2810	3042	3368	3663	3972	4002	3742	3217	2825	2741